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ABSTRACT

This report provides basic information on patterns and trends of research and development (R&D) performance in the United States itself and in relation to other countries, as well as data on public attitudes toward science and technology. Major areas addressed in the report's eight chapters include (1) the international science and technology system; (2) support for U.S. R&D; (3) science and engineering personnel; (4) industrial science and technology (examining scientists and engineers in industry, expenditures for R&D in U.S. industry, patented inventions, and university-industry cooperation in science and technology; (5) academic science and engineering (student enrollment and support, faculty roles, academic R&D, the supporting infrasructure, and other areas); (6) precollege science and mathematics education (considering student achievement, scholastic aptitude, top test scores, undergraduate student quality, courses and enrollment, international comparisons, and teachers of science and mathematics); (7) public attitudes toward science and technology; and (8) advances in science and engineering. This last chapter explores the role of sophisticated instrumentation in advancing scientific knowledge. It contains five case studies dealing with lasers, spectroscopy, superconductivity, monoclonal antibodies, and advanced scientific computing. (Detailed statistical tables are included in an appendix.) (JN)

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Letter of Transmittal

November 22, 1985

My Dear Mr. President:

In accordance with Sec. 4(j) (1) of the National Science Foundation Act of 1950, as amended, it is my honor to transmit to you, and through you to the Congress, the seventh in the series of biennial *Science Indicators* reports.

These reports are designed to display a broad base of quantitative information about U.S. science, engineering and technology to assist national policy makers in their decisions about how best to allocate scarce resources to these activities.

The critical contributions of research and advanced technology development to our international economic competitiveness and to our national security have received clear recognition from both Government and industry in recent years. The analyses in this report track these and related developments in some detail, thereby contributing to better understanding of the scientific and technological enterprise.

Like its predecessors, this report provides basic information on patterns and trends of R&D support and performance in the U.S. itself and in relation to other countries, as well as data on public attitudes toward science and technology. This report breaks new ground with chapters on science and mathematics education at the pre-college level and on the role of instrumentation in scientific advance.

I hope that this report will be of value to your Administration, to the Committees of Congress, and to the science and technology policy and research communities.

Respectfully yours,

Roland W. Schmitt
Chairman, National Science Board

The Honorable
The President of the United States
The White House
Washington, D. C. 20500

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Introduction

This volume is the seventh in the biennial *Science Indicators* series initiated by the National Science Board in 1972. It incorporates nearly fifteen years of experience in efforts to describe and analyze our complex and often elusive system for creating scientific and engineering knowledge and technological products and processes.

The series aims to provide a broad base of quantitative information about the structure and function of American science and technology to inform national policy makers as they make judgments about how best to allocate resources to these activities.

What is it that our leaders and policy makers need to know about science and technology in America? Three of the key broad policy questions are indicated below.

What kinds, levels and directions of national effort in science and engineering are necessary to:

- produce significant advance across the broad front of understanding of natural and social phenomena—basic research?
- foster vigorous inventive activity producing continuing technological advance—applied research and development?
- combine understanding and invention in the form of socially useful and affordable products and processes—innovation?

The science, engineering, and technology system is less easy to comprehend than other major functional areas of our society such as health, agriculture, or the economy. This is in good part due to the nature of its primary output—ideas. People create, communicate, and carry ideas, and dollars support people. We can and do track these things. But we still have only a very limited capability to make systematic and quantified connections with the development of fruitful ideas. Thus, our indicators remain largely *indirect* reflections of that which we truly desire to know.

Most of the elements of the science, engineering, and technology system in America can be easily specified:

- the human resources, including mainly the scientists and engineers themselves, but also their technical support and technical managers and entrepreneurs;
- the various organizational settings for the conduct of research and development;
- the substantive ideas, and research methodologies and strategies, largely embodied in the science and engineering literature;
- the physical infrastructure, including research facilities and instrumentation with the most advanced capabilities;
- the necessary financial support for all of these elements;
- and probably the least tangible, a cultural and legal context which is supportive of these efforts.

While easy to specify in principle, sheer description of each element in the system involves many problematic research issues—choice of alternative definitions, ranges of methodologies, and costs and benefits of different approaches. Even more critical are the problems of tracking and analyzing the interactions between the imperfectly measured elements—the dynamics of the system. Continuing investigation into these questions is a *sine qua non* of improved science indicators. The National Science Foundation supports research to stimulate developments in this area. Also very important are the contributions of numerous reviewers and users of the reports whose suggestions and critiques help to shape and sharpen the indicators.

Past issues of *Science Indicators* have included a chapter on "Advances in Science," which attempted to convey the excitement and substance of a few of the more rapidly advancing frontiers of scientific and engineering understanding. This report continues the tradition of a qualitative presentation, but it explores a specific theme: the role of sophisticated instrumentation in advancing scientific knowledge. Several case studies are presented. This chapter can be read in combination with the quantitative materials on instrumentation and facilities in the chapter on academic science.

The concerns expressed in the 1983 report of the National Science Board Commission on Precollege Education in Mathematics, Science and Technology, *Educating Americans for the 21st Century*, have led to the development of a chapter on this topic in *Science Indicators/The 1985 Report*. The recency of national awareness of the problems in this sector of our science and technology system means that the present surge of activity at national, State and local levels, and in the private sector, are not reflected in the currently available data. The materials presented in this chapter provide baseline information on what may often turn out to be a low point in national achievement in this area.

Science Indicators is a collective effort, as can be seen in the following acknowledgments and in Appendix II. The overall responsibility for the report derives from the statutory charge to the National Science Board. A special committee of its members provided oversight and guidance to the staff of the Science Indicators Unit of the Division of Science Resources Studies (SRS) who worked exclusively on the report and the related research. Other members of SRS, as well as staff from other NSF Directorates aided in the manuscript preparation. The Directorate for Scientific, Technological and International Affairs (STIA) assumed overall staff responsibility for the report.

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The Board is grateful to the special contributors and to those who reviewed the various chapters of the report, all of whom are listed in Appendix II. Thanks are also due to the staff of the NSF Printing Office for the production of a complex document.

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[1] Through March 1, 1985
[2] From March 4, 1985
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Overview of the U.S. Science and Technology Enterprise

Science and technology are pervasive determinants of modern life. They serve as tools for advancing the understanding of nature, for pursuing national goals, and for attacking many of the problems of U.S. society. How well they serve these purposes depends largely on the vigor of science and the inventiveness of technology. Thus, the health of the scientific and technological enterprise is a matter of major public concern. Furthermore, because of the length of the period between scientific and engineering advances and their incorporation into socially significant technologies, the health of science and engineering is not only a matter of great significance for today but also for the future. Health is, of course, a relative state, so it is generally necessary to examine the U.S. scientific and technological enterprise with reference to similar activities in other countries by contrasting the performance of its various sectors and by examining temporal trends. Since changes in aggregated entities are not necessarily driven by the same factors, it is also important to examine components separately.

An examination of the most recent available indicators reveals that the strength of U.S. science and technology, with some exceptions, has been growing steadily over the last few years, a trend which is reflected in the magnitude and vitality of the enterprise. Many indicators presented in this report support this conclusion. The number of employed U.S. scientists and engineers reached a new peak of 3.5 million. More importantly, their proportion in the U.S. workforce was at an all time high, 3.4 percent. U.S. spending for R&D reached new historic heights, not only with 1984 expenditures of $97 billion but also in constant dollar terms. The fruits of these technical endeavors kept the U.S. competitive, with high technology exports maintaining a strong share of international markets. The proportion of research articles authored by U.S. scientists in core journals, though decreasing slightly, still accounted for 35 percent of all such articles in 1982, and successful patent applications by U.S. inventors began to increase again after a long period of decline. This pattern of strength and growth was driven by an increasing awareness that modern society depends strongly on science and technology. One indicator illustrative of this phenomenon is that between 1970 and 1983 employment of scientists and engineers grew three times as rapidly as total U.S. employment. Contrary to a widely held belief, most of these professionals are not engaged in R&D, but two-thirds of them are primarily involved in the utilization of science and technology, i.e., in management, production and technical services.

Several rather more specific factors can be identified as driving forces behind recent science and technology growth. The Federal government placed a high priority on research and development, leading to average Federal R&D funding increases (constant dollars) of 4.3 percent per year during the 1980-84 period. Emphasis has been placed on defense-oriented R&D, which by 1985 accounted for 70 percent of the Federal R&D budget, and was concentrated in development of major weapon systems. Federal nondefense R&D funding actually declined in constant dollar terms (-5.5 percent/year between 1980-84), on the assumption that some of this research should be left to the purview of the private sector. Indeed, the bulk of the decline occurred in civilian development and applied research activities. In contrast, the government has increasingly emphasized the support of basic research, much of it in the university context. While staying just about level over the 1982-83 period, Federal support for basic research showed strong real dollar growth of about 7 percent between 1983 and 1984. This growth is expected to continue into 1985 but then pause in 1986.

While the government increased its R&D commitments, particularly in the defense and basic research areas, the industrial sector became increasingly aware of its long-term dependence on R&D. Industry steadily increased funding of these activities between 1980 and 1984 at an average annual constant dollar rate of 6.0 percent, a rate almost equal to the 6.7 percent rate of the previous 4 years. These high positive rates of growth of company R&D funding persisted even during the recession period of the early 1980's, thus underlining the importance industry places on this type of activity. As expected, industry concentrated its support for R&D on applied research and development. It matched the rate of growth of Federal funds in the development area and significantly increased its applied research funds by an annual average of 8.8 percent. This increase compensated for the relative flat (constant dollar) level of Federal applied research expenditures through the same period. Furthermore, even though industry's investment in basic research constitutes only 19 percent of total U.S. basic research funding, companies have increased their expenditures for this important activity at an average annual (constant dollar) rate of 9.1 percent during the 1980-1984 period, compared to a 1976-1980 rate of 5.1 percent. This increase reflected industry's appreciation of the importance of a constantly expanding fundamental knowledge base to its long-term economic competitiveness.

Consideration of R&D growth alone masks some significant recent structural changes in U.S. science and technology. The business sector, while strongly dependent on government R&D money for defense-related product lines, became the major provider of R&D funds in 1980 and has since increased its share of R&D funding steadily, accounting for 51 percent of the U.S. total in 1984 compared with the 46 percent funded by the government. Furthermore, spurred by private and governmental actions the industrial R&D scene saw the reemergence of small business R&D operations as an important component. From the low point in 1975 to 1983, there was a spectacular 20-fold growth in venture capital spent on equity acquisitions in small, high technology manufacturing businesses. Small business R&D has also been enhanced by Federal actions such as the recent Small Business Innovation Development Act, which requires that by fiscal year 1986 Federal agencies allocate up to one and one-fourth percent of their R&D grant and contract funds to small companies.

New structural forms permitting stronger interactions between the discovery of new knowledge and its application are also evolving. Such structural changes are evident in the emergence of new institutional arrangements between industry and universities, such as university-based institutes funded by industry, academic innovation centers, and university-industry cooperative research programs. These linkages derive from initiatives of both industry and academia with the encouragement of government. The results of such cooperative endeavors can be seen from such indicators as the doubling, between 1973 and 1982, of the fraction of industry-authored technical papers coauthored by scientists and engineers from academia. Also companies are experimenting increasingly with the creation of separately organized new S&T oriented venture units within the framework of their overall company structure.

A growing structural differentiation is evident in industrial R&D spending patterns. Three-quarters of all industrial R&D funds are spent by high technology manufacturing industries. However, between 1980 and 1982 the R&D investments of non-high technology manufacturing companies (-0.6 percent per year in constant dollars) lagged greatly behind those of the high technology firms (9.6 percent per year). This low growth rate takes on special importance since the strength of the U.S. commercial sector has become increasingly dependent on its ability to produce and apply new technologies. In spite of the 1984-85 strength of the dollar in foreign exchange markets, U.S. high technology firms generated trade surpluses in high technology products, while firms in other industries had increasing difficulty competing with foreign goods. However, high technology firms depend on foreign demand for a significant share of their output: the equivalent of almost 40 percent of their production is sold abroad, while less than 10 percent of the production of other manufacturing industry is exported. The U.S. firms also exhibit strength in other channels of international diffusion of commercial technology, such as foreign sales of licenses to patents and royalty and fee receipts.

Areas of R&D emphasis and interest are changing. All indicators point towards three areas of growing importance: biotechnology, engineering, and computers. For example, between 1978 and 1983 U.S. patenting in genetic engineering technologies increased by 66 percent per year. Additionally, several of the new joint university-academic ventures are in the biotechnology area, and Federal funding of agriculture related R&D has reflected concern that the agricultural sciences be at the forefront of the biotechnological revolution. The rapid and pervasive growth of computer technology has led to a shortage of professional personnel in that area. Especially acute has been the inability of academic institutions to fill faculty positions in this field as well as in several engineering fields. Furthermore, Federal R&D funding explicitly focussed on the need for more and different engineering R&D, especially in the FY 1984, 1985 and 1986 budgets. Students who are generally sensitive to emerging needs also perceived these new professional opportunities: Thus, among 1983 freshmen, engineering surpassed the social and biological sciences as the most popular selected major among all technical fields. The phenomenon was also evident in graduate study, where computer science enrollments increased by 60 percent between 1980 and 1983, with engineering showing the second highest growth of 25 percent.

The availability and quality of human resources is central to the vitality of science and engineering. Ideas, concepts and innovations come from people and it takes a long time to train scientists and engineers. The 1984 S/E labor market showed no overall shortage of scientists and engineers, though there were signs that shortages of aeronautical and electronic/electrical engineers as well as computer specialists were beginning to appear again, especially for experienced personnel. For a number of fiscal as well as demographic reasons, employment of scientists and engineers in academia has not been increasing as rapidly (15 percent) between 1976 and 1983 as industrial employment (60 percent). If this trend continues, it has major training implications concerning the availability of sufficient faculty in certain fields to teach the growing classes of science and engineering students bound for industrial jobs in these fields. This is frequently discussed as the "seed corn" problem.

Enrollments and degree production in science and engineering fields have shown renewed growth since the mid-seventies, though this pattern is not uniform among fields. The social sciences in particular have shown a general pattern of decrease, while undergraduate engineering and computer fields are booming. At the graduate level S/E enrollments grew by 7 percent between 1980 and 1983. However, 85 percent of this growth was due to foreign student participation, which was especially strong in engineering, computer sciences, and agriculture. Since 1980 the number of U.S. citizens receiving Ph.D.s in engineering and computer science has fallen. In 1982, about one-third of the Ph.D.s awarded by U.S. universities in computer science, and over half of the doctorates in engineering, were awarded to foreign citizens. Substantial and increasing numbers of young foreign scientists in these fields, as well as in mathematics, remain in the United States following graduation. Their principal destination is in the academic sector, but the numbers having firm employment plans in the industrial sector have been rising in recent years.

Several recent national reports have described serious shortcomings in the U.S. precollege science and mathematics education system. Such education and training is not only critical for future scientists and engineers, but it is also important for ordinary citizens living in an increasingly complex technological world who will have to deal with many problems that have science and engineering components. Yet, national assessments of science and mathematics achievement show that the average student, in the age groups of 13 and 17 years, knows comparatively less about these subjects than similar students did in earlier periods. Furthermore, the 1982-83 assessment reveals that if any noticeable improvements have occurred, they resulted from improvements in the type of knowledge and skills obtained from textbooks rather than in basic understanding and analytical abilities. It is also worth noting that American high school students take substantially less course work in science and mathematics than their counterparts in other major industrialized countries, and as a matter of fact, fewer courses than their parents about three decades ago.

The reports and studies referred to above have stimulated a national debate on the adequacy of U.S. secondary education in general, and on the science and mathematics portion in particular. Many new initiatives are being undertaken by local, State, and Federal governments, some cooperatively with the industrial and private non-profit sectors. The results will be discussed in future editions of *Science Indicators*.

There is a clear national need for the utilization of all available human resources in the pursuit of science and technology activities. Thus, participation of women and minorities in science and engineering employment increased significantly between 1970 and 1982. Involvement in science and technology increased on the average by about 12 percent per year for both women and blacks, growth rates which greatly exceeded those of their male (5.1 percent) and white (5.8 percent) counterparts. However, women and minorities are still underrepresented in science and engineering. In 1984, women accounted for 13 percent of all U.S. scientists and engineers—25 percent of scientists and 3 percent of engineers—while 2.4 percent of the S/E labor force were black and 2.1 percent of Hispanic origin.

A significant feature of academic science and technology policy in recent years has been the Federal response to the deterioration of the academic S/E infrastructure, especially instrumentation and facilities. Several indicators of this resource base converge: about 26 percent of all academic science and engineering research equipment (costing between ten thousand and one million dollars) is obsolete, and not in use; the stock of academic research equipment is about twice as old as equipment in comparable industrial laboratories; the median age of academic equipment systems is 6 years, and 31 percent are more than 10 years old; nearly half of departmental chairpersons view research instrumentation as "inadequate" to permit investigators in their departments to pursue their major research interests. Only 16 percent of research equipment was categorized as "state-of-the-art." In recent budgets, the Federal government has responded to this problem by increasing funds specifically intended for the acquisition of new academic research equipment. Agencies with significant new spending initiatives for this function include the National Science Foundation, the Department of Defense, and the Department of Energy.

How has the positive momentum generated over the last few years in U.S science and technology affected its relative standing in the international S&T context? The U.S. continues to play a leading role in an interdependent, international S&T system. It has a much larger research and development endeavor than any other industrialized market economy and produces a large share of the research articles, inventions, and innovations. However, in recent years the other large, advanced industrial countries have significantly increased their levels of S&T activity. Indicators of output of new scientific knowledge, of inventive activity, and of impacts of science and technology suggest that the extent of the American lead has somewhat diminished, even though the U.S. has remained highly competitive on international markets. European science and Japanese commercial technology are increasingly important to science and engineering in the United States, while in return the United States makes continuing major contributions to the international diffusion of new scientific and technological knowledge. On a normalized scale, the share of the U.S. gross national product which is devoted to R&D expenditures is approximately equal to that of other large market economies. However, the U.S., along with France and the U.K., devotes a relatively high share of its R&D resources to defense-related activities while West Germany and Japan perform relatively more civilian R&D. The Soviet Union appears to have the largest R&D endeavor in the world, but the Soviet R&D effort may not necessarily translate into a stronger relative overall science and technology system.

In summary, U.S. science and technology is vital, increasingly pervasive throughout all facets of modern society, and internationally competitive. It has experienced a period of significant real growth. With the Federal government playing a strong role, the system is swinging somewhat more towards defense-oriented activities. Increased recognition of the importance of a constantly expanding fundamental knowledge base has resulted in renewed basic research emphasis in all sectors of the economy. The academic science and engineering base has been growing and corrective actions are being taken to deal with some of its special problem areas such as research instrumentation and young investigators. Internationally, the competitive position of U.S. science and technology related activities is still strong, although the other major industrialized countries have made rapid progress.

The human resources required to drive the enterprise are being produced generally in adequate numbers, though some problems are apparent, especially in engineering and computer specialties. There is cause for concern about the adequacy of science and mathematics education of precollege students, education that is not only necessary to assure continued production of high quality scientists and engineers but also for a population that can deal effectively with the problems of an increasingly complex technological society. The strong support evidenced by the American public for science and technology, with some healthy reservations in some areas, is matched by its expectation that these activities will continue to solve major national problems and to improve the quality of their lives.

With the exception of pre-college science education, the overall picture emerging from the analysis of indicators presented in this volume can only be interpreted as very positive. However, a reorientation of Federal R&D support is taking place. This trend, coupled with an expected 1986 pause in Federal basic and academic research funding, warrants careful attention to future trends so that the momentum and continuity, so essential to effective progress in research and development, will be maintained in oncoming years.

Chapter 1

The International Science and Technology System

The International Science and Technology System

HIGHLIGHTS

- *U.S. the largest R&D performer; others are growing.* The United States plays a leading role in an interdependent, international science and technology (S/T) system. The U.S. has a much larger R&D endeavor than any other industrialized market economy and produces a large share of the research articles, inventions, and innovations which result from that endeavor. However, in recent years the principal countries have significantly increased their levels of S/T activity. European science and Japanese commercial technology are increasingly important to science and engineering in the United States, while in return the United States makes continuing major contributions to the international diffusion of new scientific and technological knowledge.

- *R&D increasing in all major countries.* R&D expenditures in the five largest advanced market economies have increased substantially since the mid-1970's. Total expenditures in the United States, Japan, West Germany, France, and the United Kingdom, measured in constant dollars, were 40 percent higher in 1982 than they were in 1975. U.S. expenditures on R&D continue to be somewhat greater than the total expenditures of the other four countries combined. The share of gross national product (GNP) which is devoted to R&D has increased steadily in all of these countries, as has the proportion of R&D scientists and engineers to the active labor force. (See pp. 4-5.)

- *Of the large market economies, the United States has the largest R&D work force.* By devoting about 2.5 percent of gross national product to R&D expenditures, the R&D endeavors of the United States, Japan, West Germany, and the United Kingdom are about the same relative size. However, if defense-related R&D expenditures are excluded, the civilian R&D efforts of West Germany and GNP, considerably higher than the 1.6 to 1.8 percentages of GNP devoted to civilian R&D in the United States, France, and the United Kingdom. (See pp. 4-6.)

- *Soviet Union supports sizeable R&D efforts.* Science and technology resource data for the Soviet Union are not as well established or available as for the other major countries. However, it appears that the R&D endeavor of the Soviet Union is the largest in the world both in volume and relative to GNP. While the Soviet definition for engineers is broader than that of the United States, estimates show that between 9 and 11 scientists and engineers (S/E's) work in R&D in the Soviet Union, significantly more than the seven S/E's in R&D per 1,000 labor force in the United States. (See pp. 5-6.)

- *U.S. leads in science degrees; USSR and Japan in engineering degrees.* In the physical and life sciences and mathematics, the United States granted 106,000 first degrees in 1982, more than twice the number granted in the Soviet Union, and almost four times as many as were conferred by Japanese institutions. However, in engineering, the United States granted about 64,000 first degrees in 1982, while institutions in Japan conferred 74,000, and the Soviet Union, 330,000. (See pp. 6-7.)

- *U.S. lead in publishing and patents is diminishing.* The United States has held a leading position in science and technology for many years. However, indicators of the output of new scientific knowledge, of inventive activity, and of the impact of science and technology on the economy suggest that the U.S. lead has diminished. The share of research articles in core journals written by U.S. scientists and engineers has fallen slightly from 38 percent in 1973 to 35 percent in 1982. The number of patent applications made abroad by U.S. citizens fell by about 50 percent between 1969 and 1982; during the same period, Japanese external patent applications grew by almost 55 percent. (See pp. 7-8.)

- *Export markets are increasingly important to high-technology industries in the United States.* In 1981, the value of exports in 11 high-technology product groups was the equivalent of 39 percent of value-added in those industries, up from 23 percent in 1972. In other manufacturing industries, U.S. exports were the equivalent of only 9 percent of value-added. (See p. 10-11.)

- *U.S. surplus in trade in high-technology goals has decreased.* The U.S. surplus in trade in high technology products indicates the competitiveness of the U.S. in international markets. The trade surplus in high technology products, measured in constant dollars, fell by over 40 percent between 1980 and 1982. However, during the same period total imports of high-technology products by the United States' major trading partners fell by about 65 percent. Thus, although U.S. exports were handicapped by a strong dollar, they took an increasing share of shrinking international markets. (See pp. 11-12.)

- *Commercial technology transfer through all channels has decreased.* The channels other than trade for the international diffusion of commercial technology have contracted in recent years. Although trade in high-technology products has fallen, it has accounted for an increasing share of international technology transfers. There were increases in the ratios of exports to imports of high-technology products and of receipts to payments of royalties and fees for the United States, Japan, West Germany, and the United Kingdom between 1977 and 1982. Thus, these countries are pursuing policies which permit the importation of goods embodying new technologies and which permit foreigners to obtain technology through licensing. However, only in the United States and the United Kingdom are the ratios of receipts to payments of licenses and fees greater than one, indicating net transfers abroad of disembodied technology. (See pp. 12-15.)

- *U.S. dominates international R&D in a few high-technology industries.* Enterprises in the United States place a relatively great emphasis on R&D in the Aerospace, Instrument, and Office Machinery and Computer industries. In 1981, about 84 percent of the privately financed R&D expenditures in the five largest industrialized market economies were made in the United States; in all industries, the U.S. share was 60 percent. The pattern of specialization in commercial technology extends to patent activity: in 1982, U.S. inventors received 32 percent more laser-related patents, but 41 percent fewer robotics patents, than predicted by the U.S. share of major-country patents in all technologies. (See pp. 15-17.)

- *Foreign students increasing in U.S. graduate schools; in a few disciplines, many remain following graduation.* In 1982, U.S. universities granted almost 3,900 doctorates in science and engineering fields—or 23 percent of all science and engineering doctorates awarded—to citizens of foreign countries. Over 53 percent of the engineering doctorates were granted to foreign students, as were over one-third of the doctorates in mathematics. Almost 80 percent of the foreign recipients of U.S. doctorates had nonresident visas, and were thus expected to leave the United States after receiving their degrees. However, in 1983 over 60 percent of the non-resident recipients of Ph.D.s in the computer sciences from U.S. universities had found employment in the United States, as had over 40 percent of the non-resident Ph.D. recipients in engineering. (See pp. 19-20.)

- *Young U.S. scientists and engineers are gaining less direct access to foreign work than they did in earlier years.* Between 1971 and 1982, the number of new U.S. science and engineering Ph.D. recipients with firm commitments to postdoctoral study abroad declined from just under 400, or 2.3 percent of U.S. science and engineering doctorates, to about 225, or 1.5 percent of science and engineering doctorates awarded to U.S. residents. Despite the health of European efforts in high-energy physics, the number of U.S. doctoral recipients studying physics abroad fell from 84 in 1971 to 17 in 1982. U.S. scientists and engineers increasingly gained access to foreign science through other channels. For example, in 1983, the number of academic exchange visas issued to foreign scholars (primarily Japanese and West Europeans) on temporary visits to the United States was over 90,000 for the first time. Research articles published in the core journals in 1982 by U.S. scientists and engineers made 46 percent of their references to foreign publications, up from 41 percent in 1973. Sixty-two percent of the citations in U.S. chemistry articles in 1982 were to the publications of foreign scientists. (See pp. 20-23.)

- *Cooperation between U.S. scientists and engineers and their foreign colleagues has increased.* Between 1973 and 1982, U.S. scientists and engineers increased their international co-authorship from 14 percent to 18 percent of all institutionally co-authored articles in core journals. (See pp. 23-24.)

The organized pursuit of knowledge is an international activity. Scientific and technological developments in one country lay the foundations for further research in laboratories elsewhere; national boundaries are highly permeable to scientific exchange. The application of new knowledge in commercial technology crosses borders, as innovators exploit their advantages in international markets. Scientists and engineers travel, correspond with their colleagues in different countries, and read without regard to the nationality of the author. A nation's ability to use the results of scientific and technological (S/T) activities conditions its ability to succeed in international political and economic competition. Thus, national policymakers look to international science and technology indicators for evaluation of the appropriateness of their country's effort. These analyses will continue to be important; international comparisons like analyses of time-trends, provide important information about the "normal" or "competitive" levels of particular S&T variables.

However, international indicators have the potential to provide another important type of information. Indicators which describe the international S/T system permit an examination of the environment in which domestic research, development, and innovation are carried out. This examination contributes increasingly to the identification and analysis of the international constraints and opportunities which face domestic S/T policy, thereby helping this policy to develop in concert with the international S/T system. The linkage of international science indicators into a coherent description of key sectors of the international S/T system is one goal of this chapter.

Further, this chapter identifies the international system in which S/T activities take place. It analyzes the effects of this system on U.S. science and technology, science and technology policy, and the U.S. economy, and describes the role of the United States in the system. The first section of the chapter compares various indicators of S/T activity in the United States with activities in other countries. The goal of this discussion is to evaluate the leading role which the U.S. plays in science and technology. The second section discusses the relationship between the international economic system and the development of commercial technology. International markets are an important source of the profits which reward successful innovation and which finance successive private R&D efforts, while rapid technological advance is a key ingredient of competitive success in many of the world's product markets. Finally, the third section emphasizes the international development and diffusion of science, including the contribution of advances in foreign countries to American research, the symbiotic relationship between foreign graduate students and American research institutions, and trends in international communication in science.

THE U.S. POSITION IN THE INTERNATIONAL SCIENCE AND TECHNOLOGY SYSTEM

The comparison of S/T activities in the United States with activities in other major advanced industrialized countries provides an indication of the strength of the U.S. science and technology endeavor. The health of the system depends in part upon the adequacy of the inputs to R&D and to other S/T activities. These inputs include both the financial and human resources which are devoted to R&D, as well as the students trained by the Nation's colleges and universities each year in different S/E disciplines.

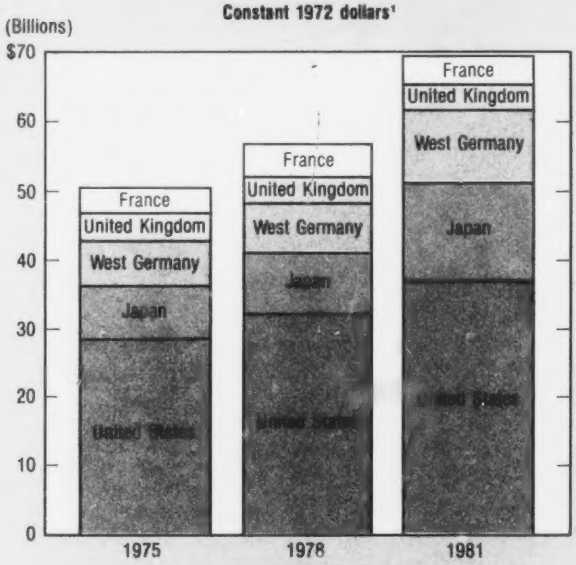
Overall indications of the relative strength of U.S. science and technology may also be gained through observation of the results of S/T activities. Successful research projects are reported in the scientific literature, while many inventions receive protection in the world's patent systems. Finally, strong technological efforts contribute to increasing productivity.

Resources Devoted to the Science and Technology System

The magnitude of R&D efforts in the United States and other countries has increased in recent years. Figure 1-1 shows the total R&D expenditures in the United States and in four other major market economies, converted into constant 1972 dollars, using purchasing power parities, to take into account inflation and differences in the purchasing power of the national currencies. In 1981, the last year for which data for all five of these countries are available, they performed about 88 percent of the R&D carried out in the 24-country Organisation for Economic Co-operation and Development (OECD), which includes almost all of the world's industrialized market economies. Along with the Soviet Union, these countries carry out almost all of the world's S/T activities.[1]

Figure 1-1

Expenditures on research and development in selected industrialized countries



¹The GNP or GDP implicit price deflators are used to convert expenditures in national currency to constant 1972 prices. The 1972 purchasing power parities are then applied to convert to U.S. dollars.

See appendix table 1-5.

Science Indicators—1985

Across the 7 years examined in figure 1-1, the U.S. share of major country R&D expenditures remained essentially constant. The real level of R&D expenditures may have increased slightly, but there has been no discernible shift in the distribution of expenditures among the five countries studied here. The United States accounts for about half of the five-country total and Japan for about one-fifth; the other three countries spend relatively less on R&D.

These increases in R&D expenditures in the major countries should be treated with caution. During the 1970's, the prices for inputs to R&D activities increased at a greater rate than did the overall price level, as measured by the GNP deflator. There have been greater increases in the relative price of R&D in West Germany and Japan than in the United States, so that the slight fall in the U.S. share of the five-country total, in favor of West Germany and Japan, has little significance. If the trend toward relatively large increases in R&D costs continues into the 1980's, then figure 1-1 probably overstates the real increase in the resources devoted to R&D.[2]

Analyzing the number of scientists and engineers (S/E's) employed in R&D avoids the problems associated with transforming expenditure data into terms which are common across both time and countries. Although there are some differences in the definitions used by different countries to count S/E's in research and development, these definitions have remained relatively constant over time. Thus, more robust analyses of the trends in R&D activities can be achieved.

Figure 1-2 compares the relative R&D efforts of six leading countries, as indicated by the proportion of the labor force employed as scientists or engineers. These data confirm the tentative conclusion of figure 1-1 that in recent years there have been substantial increases in both absolute and relative terms in R&D efforts of the major R&D-performing countries. Since 1976, the proportion of the U.S. labor force employed in R&D has increased steadily, while in recent years the other major countries have also increased the relative emphasis that they place on R&D.

The absolute number of S/E's engaged in R&D has increased substantially in all these countries. (See appendix table 1-1.) Between 1965 and 1982 this number more than doubled in all these countries, except in the United States, which employed about 45 percent more research S/E's in 1982 than it did in 1965. During the same period,

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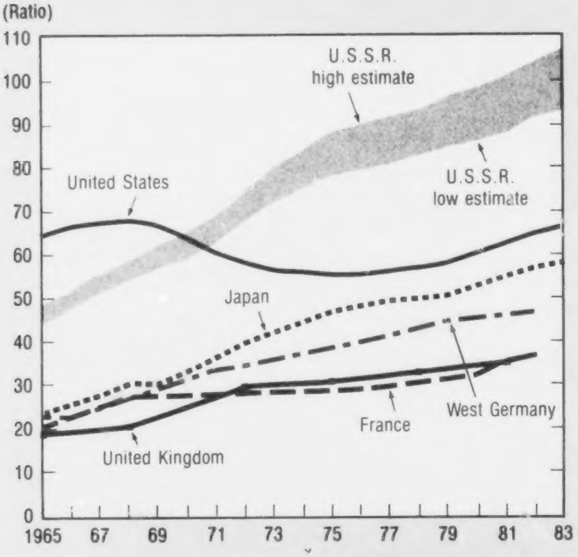
[1] See OECD (1984a), p. 70.

[2] See Mansfield, et al. (1983).

Figure 1-2

Scientists and engineers[1] engaged in research and development per 10,000 labor force population by country



[1]Includes all scientists and engineers on a full-time equivalent basis (except for Japan, whose data include persons primarily employed in R&D).

NOTE: A range has been provided for the U.S.S.R. because of the difficulties inherent in identifying the relevant categories of Soviet personnel.

See appendix table 1-1. Science Indicators—1985

the U.S. work force as a whole also increased by about 45 percent.

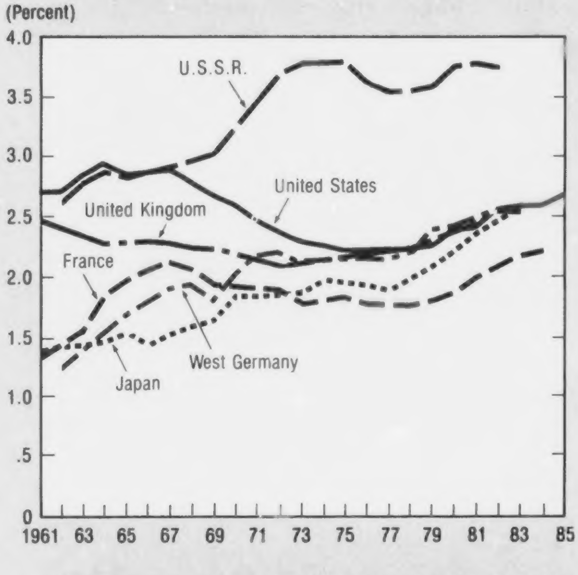
The increasing size of the R&D work force in the United States and the other major R&D performing countries has been accompanied by growth in national expenditures on R&D. Since 1978, the proportion of gross national product (GNP) which the United States devotes to R&D has grown steadily, a measure of relative R&D expenditures, reversing a long period of falling relative expenditures on R&D. In recent years, the other large market economies have also increased their R&D efforts, so that the United States, Japan, West Germany, and the United Kingdom now place a similar relative emphasis on R&D, while the relative R&D expenditures of France are somewhat lower.

Figures 1-2 and 1-3 show that the Soviet Union maintains a relatively larger R&D effort than the United States or the other market economies. For over 10 years, the Soviet Union has apparently devoted a larger share of its GNP to R&D and has employed more scientists and engineers in R&D compared to its labor force than have the other countries analyzed here. Because of the great differences between the Soviet system and the market economies, comparisons of levels of activity require caution. However, as both the ratio of S/E's engaged in R&D to the total work force, and the share of R&D expenditures in GNP, have been estimated according to consistent definitions,[3] some confidence may be attached to the trends which are displayed. The trends in the last decade are more ambiguous, as the proportion of R&D to GNP has stagnated.

The increases in Soviet R&D activity seem to be driven by increased technical activity in the "branch and department system,"[4] comprised of the laboratories which are attached to the production ministries and departments. (See appendix table 1-3.) Between 1970 and 1982, the number of scientific workers[5] in the branch and department system increased by more than 96 percent, leading the increase in

Figure 1-3

National expenditures for performance of research and development[1] as a percent of gross national product by country



[1]Gross expenditures for performance of research and development including associated capital expenditures (except for the United States, where total capital expenditure data are not available). Estimates for the period 1972-1980 show that the inclusion of capital expenditures for the United States would have an impact of less than one-tenth of one percent for each year.

See appendix table 1-2. Science Indicators—1985

the number of scientific workers as a whole. The increasing Soviet effort has therefore been concentrated on the more "applied" establishments, which are generally found in the branch and department system. Meanwhile, the number of researchers in the colleges and universities and in the laboratories attached to the Soviet Academies of Science increased at a much lower rate (between 21 percent and 68 percent from 1970 to 1982). The importance of the increasing Soviet R&D activity, both absolutely and relative to the market economies, depends largely on analyses of the efficiency with which the Soviet production ministries manage applied R&D.

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[3] The data on R&D S/E's and R&D expenditures in the Soviet Union have been compiled by an NSF contractor to match the definitions used by the United States and the other market economics discussed here. In the process of developing these estimates, the contractor has benefitted from detailed technical discussions with knowledgeable Soviet officials. The range that is provided for R&D reflects alternative assumptions concerning the research activities of scientifically-trained administrators in Soviet research establishments. (See Campbell (1984).)

[4] See Campbell (1984), p. 39.

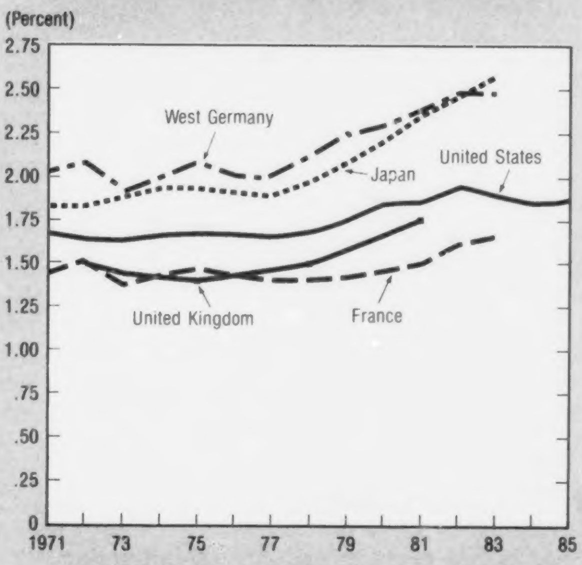
[5] "Scientific Workers" is a Soviet S/T personnel concept, including everyone with an advanced degree in science and engineering and everyone conducting research in a scientific establishment or teaching in a higher education institution. See Ailes and Rushing (1982), p. 94.

The analysis of R&D activities in the market economies must distinguish between defense-related R&D and other research and development. Defense-related R&D is not primarily oriented towards a nation's trade competitiveness, its public health, or other non-defense objectives of R&D. Non-defense R&D is defined in this chapter as the difference between national R&D expenditures and Government-supported R&D related to defense. This measure divides the five largest industrialized market economies into two groups. Japan and Germany direct relatively high shares of their national income toward non-defense R&D, while the United States, the United Kingdom, and France spend relatively lower amounts. Although total R&D expenditures have increased substantially in West Germany and Japan, Government funding of defense R&D has remained quite low. In contrast, in the United States, France, and the United Kingdom, increases in R&D funding were concentrated in the defense-related areas during the early and mid-1970's, so that the share of GNP devoted to non-defense R&D was stable or falling. Non-defense R&D has increased relative to GNP only during the last 10 years in these countries.

The ranking of countries by the proportion of GNP which is devoted to non-defense R&D expenditures (see figure 1-4) is similar to the ranking of countries by the percentage of national R&D expenditures which is financed by industry. (See appendix table 1-4.)[6] In 1981, between 41 and 49 percent of the national R&D effort was financed by private sources in the United States, the United Kingdom, and France, while in Germany and Japan the private shares were 57 and 62 percent, respectively. At the same time, funding of defense R&D represented between 49 and 55 percent of total government R&D funding in the United States, the United Kingdom, and France, but only 9 percent in West Germany and 2 percent in Japan. As the share of national R&D effort which a country devotes to defense-related activities increases, the resources that it can devote to business-related activities decrease. The low amounts which the governments of West Germany and Japan spend on defense R&D reflect in part the constitutional and legal constraints placed on them at the end of World War II. While the policies of the United States, France, and the United Kingdom have evolved to encourage strong defense capabilities in Japan and West Germany, the latter countries maintain small defense R&D efforts, particularly when compared to the strength of their non-defense R&D activities.

Figure 1-4

Estimated ratios of non-defense R&D expenditures¹ to gross national product (GNP) for selected countries



¹National expenditures excluding Government funds for defense R&D.

See appendix table 1-4.

Science Indicators—1985

The data which are examined above describe the magnitude of each country's R&D endeavor. In the long run, this endeavor is constrained by the ability of each nation's science education system to produce succeeding generations of S/E's. However, it is difficult to compare the "production" of the higher education systems of different countries, as the curricula are different and the degrees and credentials convey various meanings. While the levels of enrollment in, or graduation from, the educational systems of different countries may not directly predict the future strengths of those countries, such data may give indications of the disciplinary emphasis of the countries, while the trends in the numbers of degrees granted may indicate the overall health of the S/T endeavors in different countries.

Overall, the Soviet Union confers over twice as many first degrees every year in the S/E disciplines as the United States does. (See figure 1-5.) Soviet education is concentrated heavily in engineering—39 percent of all baccalaureates issued in the USSR in 1982 were in engineering, as opposed to 7 percent in the United States. Japanese higher education also concentrates on engineering. In 1982, about 74,000 degrees were conferred in engineering, (compared to 64,000 in the United States), representing 74 percent of Japanese first degrees in the natural sciences and engineering. The undergraduate curriculum in both Japan and the Soviet Union seems competitive with the U.S. curriculum. However, the curriculum in the United States may be more

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[6] These data are derived from regular surveys by OECD of the socio-economic objectives of government support for research and development, provided by officials of the different governments. See OECD (1984b), pp. 15, 49.

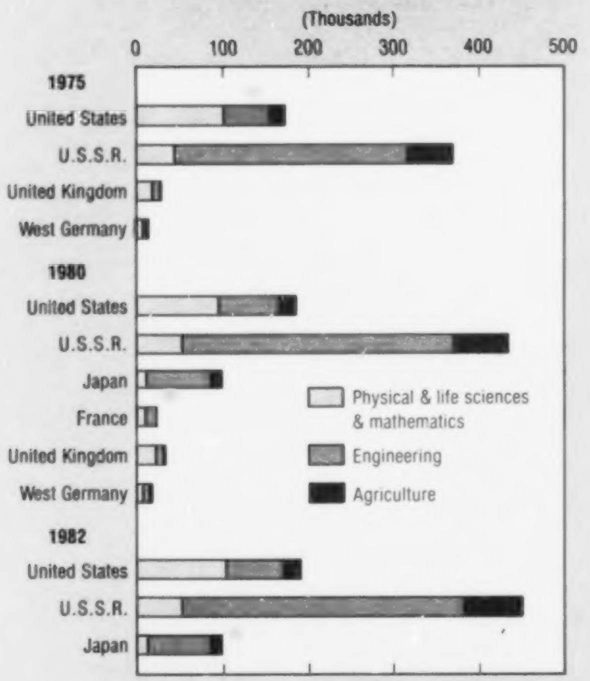

Figure 1-5
First degrees conferred by higher education institutions in natural sciences and engineering for selected countries

See appendix table 1-6. Science Indicators—1985

flexible, and may place a greater emphasis on creativity and applications than the curricula in Japan or the Soviet Union.

Colleges and universities in the United States place a greater emphasis on training in the physical and life sciences and in mathematics relative to all S/E disciplines than do the other countries examined here (except for the United Kingdom, which also trains relatively few engineers). More than twice as many U.S. students received bachelor's degrees in these three disciplines than did students in the Soviet Union (106,000 degrees in the U.S., versus 52,100 in the Soviet Union). The physical and life sciences and mathematics accounted for well over half (56 percent) of U.S. natural sciences and engineering first degrees, as opposed to only 12 percent in Japan and the Soviet Union. The share of engineers among first degrees conferred in the natural sciences and engineering in West Germany and in France is higher than it is in the United States and the United Kingdom, but lower than the shares in Japan and the Soviet Union.

The Outputs of Science and Technology

The discovery or development of new knowledge is frequently marked by identifiable events, which can often be counted or otherwise turned into indicators of the output of R&D. Researchers publish papers in journals; these are then catalogued by a variety of services to permit easier reference by subsequent researchers. These services can provide valuable information about the geographical and disciplinary distribution of important articles. New and improved products are developed which can be profitably sold in the world's markets. To prevent inventions from being imitated, which would lead to unprofitable competition, inventors frequently apply for patents in the countries where the new product will be sold. The number of patents issued by different patent authorities indicates the frequency with which inventors develop potentially profitable new ideas; it is an indicator of inventive activity.

Scientific Literature. The relative strength of U.S. science and technology, particularly in basic and applied research, is indicated by the share of articles which are written by U.S. scientists and engineers in the world's leading journals. (See table 1-1.) Over the past decade, the proportion of articles written by U.S. scientists has tended to fall slightly, the decrease being greatest in mathematics and in biology. This indicator is strictly comparative, analyzing the output of U.S. scientists in relation to their peers in other countries. The third section of this chapter considers in greater depth the implications for U.S. science of increasing scientific activity in other countries, particularly where the results of that activity are readily available to researchers in the United States.

The strength of U.S. science can be further evaluated by analyzing its contribution to subsequent work. Scientific progress involves the continuing enlargement, contradiction, and generalization of prior results. The contribution to science represented in an article may be indicated by the number of times it is cited in subsequent publications. In table 1-2, the share of citations to U.S. publications is divided by the U.S. share of publications in each field of science, to normalize for the greater number of U.S. articles which are available for citations. Overall, the U.S. research endeavor has a major impact on subsequent science. The U.S. share of citations in each field is between 18 and 80 percent higher than the U.S. share of publications.

Patents. Data on patent activity permit some overall comparisons of the output of inventors in different countries. An inventor can seek patent protection for his or her invention in many different countries. However, patenting involves various costs, such as application and maintenance fees, and the expenses of preparing the application and defending the patent. In each country, the inventor decides whether the potential profits that patent protection offers justify the costs of protection. An invention which offers greater per-unit advantages or affects high-volume products, receives applications in more countries than does a less significant invention.[7] Thus, the number of external patent applications is weighted in favor of commercially or technically significant inventions.

Between 1969 and 1982, inventors from most of the major industrialized market economies steadily decreased their applications to patent offices outside their home countries. (See figure 1-6.)[8] The decrease was sharpest for the U.S. and the United Kingdom, where residents applied for

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[7] See Soete and Wyatt (1982).

[8] Only applications to patent offices in countries which belong to the World Industrial Property Organization (WIPO) are included.

Table 1-1. U.S. share of world scientific and technical articles[1], by field: 1973, 1981, and 1982

Field[2]	1973	1981	1982
	Percent		
All fields	38	35	35
Clinical medicine	43	41	41
Biomedicine	39	39	40
Biology	46	37	38
Chemistry	23	20	21
Physics	33	28	27
Earth and space sciences	47	42	42
Engineering and technology	42	38	38
Mathematics	48	36	37

[1] Based on the articles, notes, and reviews in the influential journals carried on the Science Citation Index. 1973 data are based on over 2,100 journals of the 1973 Index, while 1981 and 1982 data are from the 3,500 journals of the 1981 Index.

[2] See appendix table 1-8 for the subfields included in these fields.

See appendix table 1-7.

Science Indicators—1985

Table 1-2. Relative citation ratios[1] for U.S. articles[2] by field:1973 and 1980

Field[3]	1973	1980
World citations to U.S.:		
All fields	1.40	1.40
Clinical medicine	1.36	1.35
Biomedicine	1.42	1.40
Biology	1.08	1.15
Chemistry	1.66	1.75
Physics	1.53	1.54
Earth and space sciences	1.38	1.44
Engineering and technology	1.28	1.24
Mathematics	1.24	1.22
Non-U.S. citations to U.S.:		
All fields	1.03	0.85
Clinical medicine	1.02	0.82
Biomedicine	1.09	0.92
Biology	0.69	0.55
Chemistry	1.20	1.01
Physics	1.18	0.99
Earth and space sciences	1.06	0.96
Engineering and technology	0.90	0.61
Mathematics	0.89	0.64

[1] A citation ratio of 1.00 reflects no over- or under-citing of the U.S. scientific and technical literature, whereas a higher ratio indicates a greater influence, impact or utility than would have been expected from the number of U.S. articles for that year. For example, the U.S. chemistry literature for 1973 received 66 percent more citations from the world's chemistry articles published in 1973.

[2] Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the 1973 Science Citation Index Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-7.

[3] See appendix table 1-8 for a description of the subfields included in these fields.

See appendix table 1-9.

Science Indicators—1985

about half as many patents abroad in 1982 as they did in 1969. In contrast, over the same period Japanese inventors increased their foreign patent applications by about 54 percent.

Changes in levels of patent activity might reflect the evolution of the competitive environment, shifts of inventive activity into fields where secrecy is maintained, or other factors which may be unrelated to trends in the underlying level of inventive activity. However, firms and inventors in all countries face similar conditions in international markets. Increases in the international patent activity of Japanese inventors, accompanied by decreasing activity elsewhere, cannot be a result only of changing patenting conditions. Instead, figure 1-6 suggests that at least in relative terms, Japanese inventive activity continues to increase, compared to the performance of the United States and the other major countries studied here.

Productivity. Over time, successful inventive and innovative activity, and efforts to adapt and adopt innovations from foreign sources, should result in increases in an economy's ability to produce goods and services at low cost. Increasing productivity, and the resulting improvements in the standards of living of the Nation's citizens, are important outcomes of the R&D endeavor. One measure of the impact of science and technology on society is the value of the production accounted for by each employed person. Gross domestic product (GDP) measures the value added by firms and individuals in each country. GDP per employed person reflects many factors, including the expertise of the work force; the quantity and quality of the machines which the work force uses; the availability to farmers of fertile land; the distribution of the work force in different industries; and the methods, or technology, which the workers use to transform raw materials into finished products. Analyses have been made to identify the sources of productivity growth,[9] which usually define technological change as the causal factor for otherwise unexplained productivity growth.

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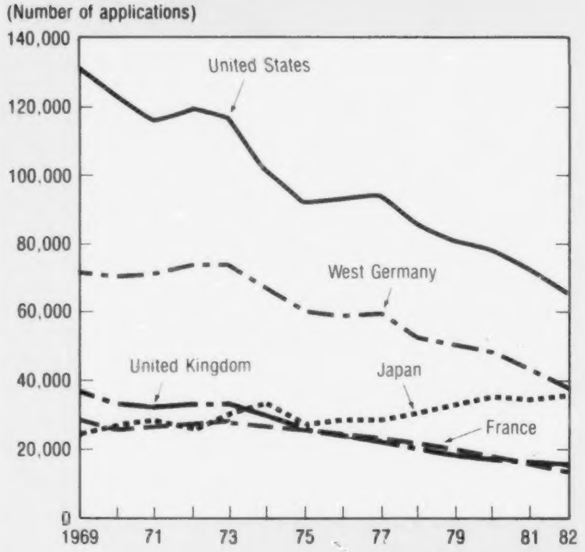
[9] See, for example, Denison (1980, 1982).

Figure 1-6
External patent applications by residents of selected countries



See appendix table 1-10.

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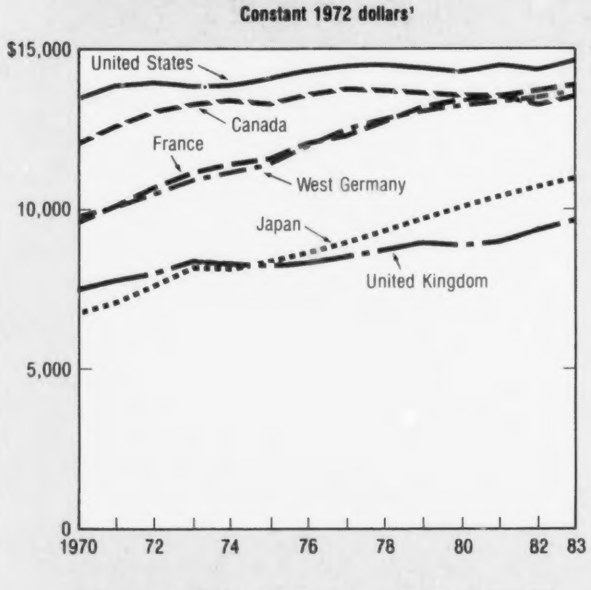
Figure 1-7 shows that, after correcting for inflation, GDP per employed person increased with fluctuations in the six largest market economies studied here. The productivity measure increased by over 25 percent in four countries: Japan, West Germany, France, and the United Kingdom. The increase was much less, about 12 percent, in Canada and in the United States. In the latter two countries, employment grew substantially—40 percent in the United States and 51 percent in Canada. This trend held down labor productivity both because of the reduction in capital availability per worker and because of the lower productivity of younger, less experienced workers. In France, employment grew only slightly, and in West Germany and in the United Kingdom it fell. Of the countries discussed here, only Japan was able to substantially increase productivity while bringing large numbers of new people into the work force. Nevertheless, at the end of the period the United States still had the highest productivity among these countries, while only the United Kingdom had lower productivity than Japan.

COMMERCIAL TECHNOLOGY IN THE WESTERN ECONOMIC SYSTEM

The application of science to the development of new technologies is a central feature of modern life. New products fill previously unmet needs and new processes permit lower-cost production. These applications transform markets, create new industries, and alter the international pattern of production and trade. Employment and investment in the United States depend in part upon the competitiveness of U.S. firms in foreign markets; thus, the introduction of new commercial technology is one key aspect of the United States' competitive thrust. This section concentrates on the competitive strength of U.S. technology and on the international economic environment in which the development of new commercial technology takes place.

In the market economies, a firm invests in R&D to increase its profits—either by producing a commodity at a lower cost or by introducing a new product to the market. In either case, a key to these profits is the size of the market that the firm faces. The United States has had the advantage of large size in the development of commercial technology; firms in the United States with innovative products sell without barrier in the largest and richest market in the world. Of course, U.S. firms do not restrict their activities to the American market. If a firm can profitably sell its products overseas, so that the expected returns from each R&D investment increases, then the firm will be willing to undertake a larger number of R&D projects.[10] Furthermore, as volume increases, the R&D cost per unit falls, making incremental R&D investment less expensive. The manner in which firms participate in the international markets for technology and technology-based products may affect the location of employment, the international diffusion of technology, and other characteristics of the international economic system. This section therefore begins with

Figure 1-7
Real gross domestic product per employed person in selected countries



[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

See appendix table 1-11.

Science Indicators—1985

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[10] See Mansfield, et al. (1977), p. 196.

analyses of several indicators of the international marketing and diffusion of commercial technology.

As firms in the United States and elsewhere compete in the development and exploitation of new technologies, national technological strengths and weaknesses may appear. Patterns of specialization in commercial technology result among the countries whose firms participate in the international markets for technology. While specialization may discourage duplication of effort in the international S/T system, tensions may develop as governments attempt to protect a national presence in particular technologies. This section therefore concludes with a discussion of the extent to which patterns of specialization in commercial technology have developed, and examines indicators of government policy in different countries which affect specialization and concentration.

The International Diffusion of Commercial Technology

The impact of U.S. science and technology extends far beyond the Nation's boundaries. New products and processes reach markets in foreign countries as well as in the United States; access to these markets offers innovative firms profits which encourage private investment in R&D. The profitability of commercial S/T development depends in part on the ability of firms, from the United States as well as from other countries, to exploit technological advantages through direct investment, licensing and consulting agreements, and exports of high-technology products. Indicators of the overall level of technology transfers describe the opportunities for profitable international operations which innovative firms from all countries face, as well as the relative technological strength of firms from individual countries. Finally, indicators of the form which the technology transfer takes indicate the policies of the recipient countries toward foreign technology, the strategies of the transferring firms, and the ability of these firms to maintain control in the future over the commercial exploitation of new technologies.

This report uses measures of three forms of international technology transfer: the export of "technology-embodying" products, the establishment or expansion of subsidiaries through foreign investment, and the transfer of "disembodied technology" through the sale of patent licenses and blueprints.

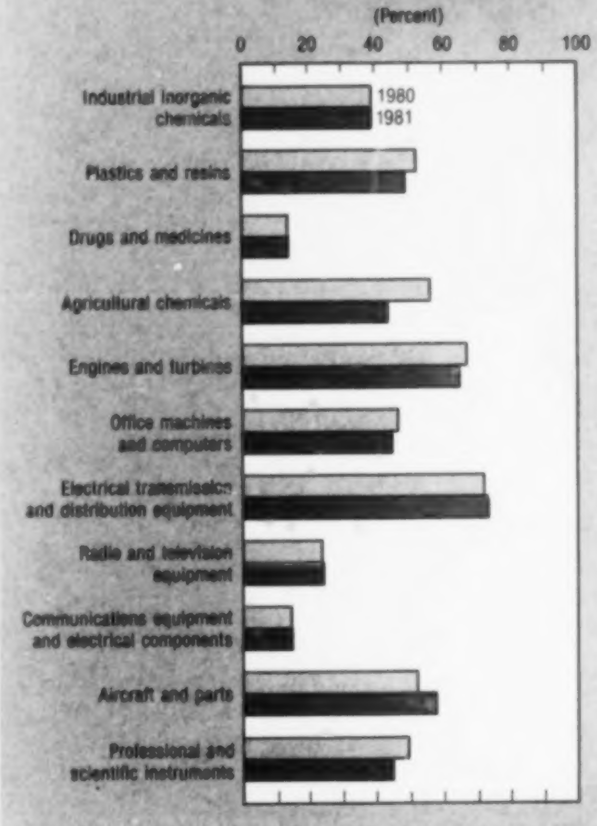
In the discussion which follows, these three channels for the diffusion of technology will be treated as alternatives; firms choose one channel in preference to another. Of course, some direct investment is directed to the establishment of trading companies, which complement export efforts. However, this chapter generally uses direct investment in manufacturing industries, which involves the establishment of production facilities overseas and therefore substitutes for exports as a channel for the international diffusion of commercial technology.

Trade in High-Technology Products. The most concrete expression of a country's technological competitiveness is its ability to sell the products which embody technological advantage on the world's markets. Exports in general enable a country to import goods from abroad which are either not available at home or are available only at high prices. In addition, exports of manufactured goods provide increased employment in the exporting industries, tax revenue to the government, and other advantages. Finally, where the exported good embodies a technological advantage, overseas sales provide a greater volume over which to distribute the cost of the R&D investment, increasing the likelihood that innovative activities will be profitable. Exports of high-technology products are thus one channel for the profitable international diffusion of technology.[11]

A high proportion of the goods produced by American firms in high-technology products is destined for foreign markets. Figure 1-8 shows that in all of 11 high-technology product groups, the proportion of exports to production, as measured by value added, increased between 1972 and

Figure 1-8

U.S. exports of high-technology products, as a percent of output[1]



[1]Shipments by manufacturing industry.

See appendix table 1-12.

Science Indicators—1985

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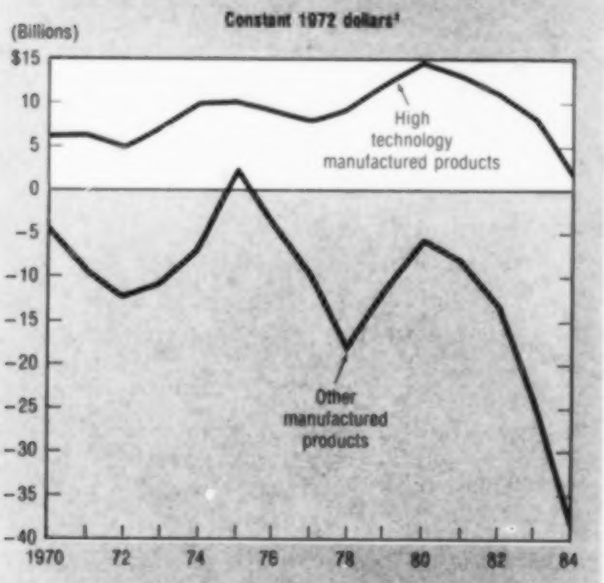
[11]The high-technology products in this analysis are those which have significantly higher ratios of direct and indirect R&D expenditures to shipments than do other product groups. Direct R&D expenditures are those made by the firms in the product group, while indirect R&D describes the R&D content of input products, calculated from an input-output table. See Davis (1982.)

1982, particularly during the most recent 2 years. In 1982, exports of Electrical Transmission and Distribution Equipment were over 70 percent of output, while exports of Engines and Turbines and of Aircraft and Parts were over half of the value added in those industries. For the 11 high-technology groups as a whole, this ratio grew from 23 percent in 1972 to 38 percent in 1982. Exports are much less important to the manufacturing industry outside the high-technology area. In 1982, exports amounted to only 9 percent of output in these industries.

The overall patterns of trade in high-technology products reflect the competitiveness of U.S. commercial S/T, the openness of the international system to this channel for the diffusion of technology, and the strength of the U.S. dollar. The trade balance in high-technology products (see figure 1-9) measures the overall competitiveness of U.S. technology by subtracting foreign sales to the domestic market from U.S. exports. After accounting for inflation, the U.S. balance in 1983 was the lowest it had been since 1973. The steady decline in the high-technology trade balance since 1980 has resulted from the simultaneous increase in imports and decrease in exports, marking a departure from the experience of the previous decade. Except for a small drop in the volume of high-technology exports between 1974 and 1975, U.S. exports of high-technology products increased in real terms during every year between 1970 and 1981. Fluctuations in the balance in earlier years resulted from changes in the rate of growth of imports of high-technology products.

Figure 1-9

U.S. trade balance¹ in high-technology and other manufactured product groups



¹Exports less imports.
²GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
See appendix table 1-13.

Science Indicators—1985

Since 1980, the U.S. trade surplus in high-technology products has decreased steadily in real terms. This trend coincides with a period when the U.S. dollar has reached unprecedented heights in international currency markets, resulting in high prices for U.S. goods in foreign markets and low prices for imported goods in the United States. The strength of the dollar has undoubtedly handicapped U.S. high-technology firms in international competition and is at least partly responsible for the recent decline in the high-technology trade surplus.

The high-technology trade balance has followed the same general trend as the balance in other manufactured products, with two important exceptions. First, the United States has experienced a continuing trade surplus in high-technology products, while trade in other manufactured products has generally been in deficit. Second, the high-technology surplus has tended to grow over time, moving in the opposite direction from the increasing deficits in other manufactured products. Thus, since 1970 U.S. firms have been more competitive in high-technology products than in other manufactured products.

During earlier years, decreases in the high-technology trade surplus accompanied booms in the U.S. domestic economy, as U.S. demand outstripped supply and drew in imports. The surplus increased during recessions, as demand for imports slackened. Export demand was independent of the domestic business cycle, and grew steadily. But between 1980 and 1982 the balance fell during a recession, partly because of the sustained fall in high-technology exports. The performance of exports in other manufactured products has been even weaker, ruling out a shift away from high-technology products in the export-product mix.

The drop in U.S. exports of high-technology products may reflect either shrinkage of the international market for these products, or a loss of competitiveness on the part of the United States because of the strength of the dollar, or other reasons. Total imports of high-technology products by the major trading partners of the United States is a proxy measure for the size of the potential market for U.S. exports of these products. Using a slightly different data set from that analyzed above,[12] U.S. exports of high-technology products grew much less during the period of 1970 to 1982 than did imports of these products by Japan, West Germany, France, the United Kingdom, and Canada. Imports by these five countries increased by 180 percent, while U.S. exports increased by 145 percent. However, between 1980 and 1982, U.S. exports of high-technology products fell by 8 percent, while total imports by the five country groups fell by 16 percent. Thus, during the period of the greatest decreases in the high-technology trade surplus, the potential market for U.S. exports contracted sharply, suggesting that the United States was not losing its technological competitiveness at the end of the period. Indeed, considering that during the 2 years of the decline the dollar appreciated with respect to all the major countries (making U.S. products relatively expensive in international markets), the ability of U.S. producers to maintain or increase their shares of a contracting market demonstrated continuing technological strength.

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[12] The OECD list of high-technology products excludes Guided Missiles and Spacecraft; Ordnance and Accessories; Agricultural Chemicals; Electrical Transmission and Distribution Equipment; and Radio and Television Equipment. The OECD data are based on the Standard International Trade Classification, while the Department of Commerce data are based on the United States SIC. See Hatzichronoglou (1983), p. 63.

Direct Investment Overseas. Firms with some advantage over enterprises in other countries can set up a subsidiary, or expand an existing subsidiary, to exploit this advantage. Direct investment, where the investor retains control over the use of the invested funds, may involve the establishment of a subsidiary or the purchase of an existing foreign firm; infusions of additional funds into an existing subsidiary; or the reinvestment, rather than repatriation, of the parent firm's share of subsidiary's profits. To indicate the success of American firms in operating abroad, the direct investment of U.S. firms abroad can be examined. This is the value at the end of each year, stated in terms of historical cost, of the holdings of U.S. enterprises in subsidiaries overseas. This measure reflects both net new investment—infusion of additional capital—and the reinvestment of the parent company's share of profits in the subsidiary. Thus, the direct investment position reflects both the openness of foreign countries to operations by U.S. firms, and the ability of U.S. firms to operate profitably in those countries.

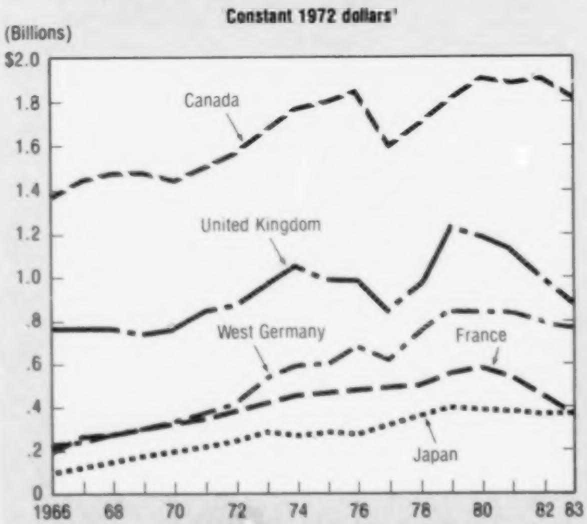
Firms in non-manufacturing industries—such as mining, petroleum, banking, finance and insurance, and trade—invest overseas for reasons other than the exploitation of technological advantage. For example, they may be seeking raw materials, improved access to capital markets, or tax havens. Such reasons also exist in the manufacturing industries. However, the latter firms may also earn profits from the overseas markets through the production and sale of goods, as well as through the extraction of country-specific advantages. The presence of manufacturing firms in a country is a result of competitive strength, which is in part a reflection of technological advantage. Favorable conditions within the host country, such as lower labor costs, may attract direct investment. However, the foreign firm's ability to compete successfully in the host country depends on advantages over local firms, such as those provided by access to more advanced technologies. Studies have shown that direct investment is indeed a preferred channel for the exploitation of technological advantage.[13] Thus, the direct investment position abroad serves as a useful indicator in the manufacturing industries of the openness of the international market for technologies and of the use which U.S. manufacturing firms make of those markets.

U.S. direct investment in manufacturing is heavily concentrated in a small number of countries. In 1983, 47 percent of the direct investment position in these industries was in Canada, the United Kingdom, and West Germany. U.S. direct investment in France and Japan accounted for, respectively, 5 percent and 4 percent of the total direct investment position in manufacturing. In 1982, 45 percent of the direct U.S. investment position in manufacturing in these countries was in the Chemical and Machinery industries. The trends in these positions are shown in figures 1-10 and 1-11 and measured in constant dollars.

Until the mid-1970's, the direct investment position of U.S. firms in these industries grew steadily. Since that time, however, the position has fluctuated, and has generally fallen since 1981. The conditions which encouraged direct investment in previous years have since disappeared. A combination of factors may have worked to reduce the size of U.S. direct investments overseas. Some of the sluggish behavior can be attributed to adverse economic conditions, such as corporate illiquidity and high interest rates.[14] Some of the reduction results from valuation adjustments to reflect the falling value of foreign investments in terms of U.S. dollars. In addition, the improved profitability of investment within the United States, following the 1981 Tax Act, may have discouraged U.S. direct investment overseas. However, trade in high-technology products, which is one alternative to direct investment overseas as a channel for the international diffusion of commercial technology, has also decreased. Hence, U.S. firms are not substituting exports for direct investment. Whether they are instead increasing their use of the third channel for the diffusion of technology, the sale of patent licenses, and the establishment of other agreements, can be determined through the analysis of data on receipts and payments of royalties and fees.

Figure 1-10

Direct investment position of U.S. chemical firms in selected countries



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
See appendix table 1-13.

Science Indicators—1985

License Fees and Payments. A third channel for the exploitation of a technological advantage is the direct sale of technology—in the form of patent licenses, plans, and blueprints—and consulting agreements. Such sales can be made either to independent firms or to subsidiaries and affiliated firms. In the latter case, the resulting royalty and fee payments are one form of intra-company funds transfer, and may be related less to the actual value of the

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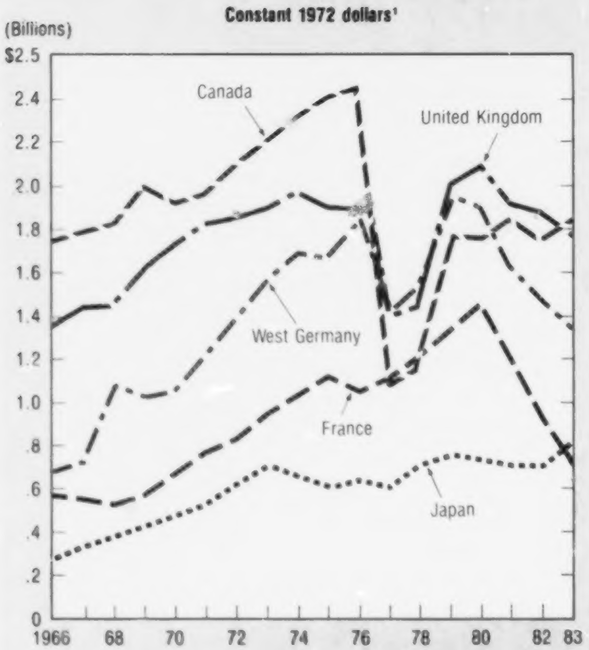
[13] See Mansfield, et al. (1979).

[14] See Wichard (1983), p. 14.

Figure 1-11
Direct investment position of U.S. machinery firms in selected countries



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
See appendix table 1-15 Science Indicators—1985

technology and technical assistance than to the firm's global tax strategy or to host governments' technology policies. In contrast, the sales of technology to an independent firm is an "arm's-length" transaction; the buyer and seller must agree on the price for the technology, which will provide a reasonable approximation of its true value. Therefore, this report analyzes, where possible, the flows of royalty and fee payments only between unaffiliated firms.

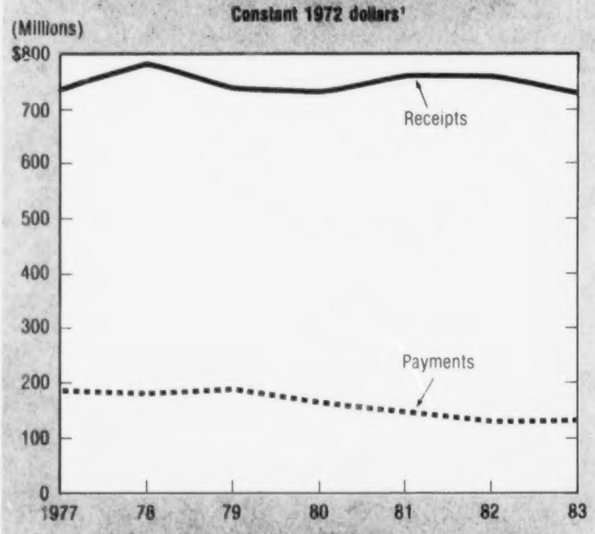
Receipts of royalties and fees by U.S. firms from unaffiliated foreign firms and individuals grew steadily in real terms from the 1960's until 1978. Receipts then fell slightly and have fluctuated in recent years. (See figure 1-12.) The real level of technology transfer in 1982 is lower than that which occurred in 1978. From 1979 through 1982, payments by U.S. firms to unaffiliated foreign firms and individuals fell steadily. These indicators show a decrease in licensing activity in both directions since 1977; hence, U.S. firms are using this channel of international technology transfer somewhat less than they have in the past.

The decrease in royalty receipts and payments accompanies changes in the geographical distribution of this activity. In 1982, 79 percent of U.S. royalty and fee receipts from unaffiliated firms and individuals came from other developed countries, down from 89 percent in 1972. Thus, while technology transfers in this form are still predominantly toward other developed countries, transactions with other developed countries have decreased. In contrast, the channel is increasingly used for transfers to less-developed countries. Payments by the five largest market economies are primarily to other members of the group. Hence, the trend toward the increasing gap between receipts and payments (see figure 1-13) shows the growing importance of transfers to countries outside the group. The decrease in U.S. licensing in advanced countries parallels the evidence provided by the data on direct investment abroad by U.S. firms (see figures 1-10 and 1-11), suggesting that these firms are having increasing difficulty exploiting their technological advantages, particularly in the other advanced countries.

International Diffusion of Technology: the Alternatives

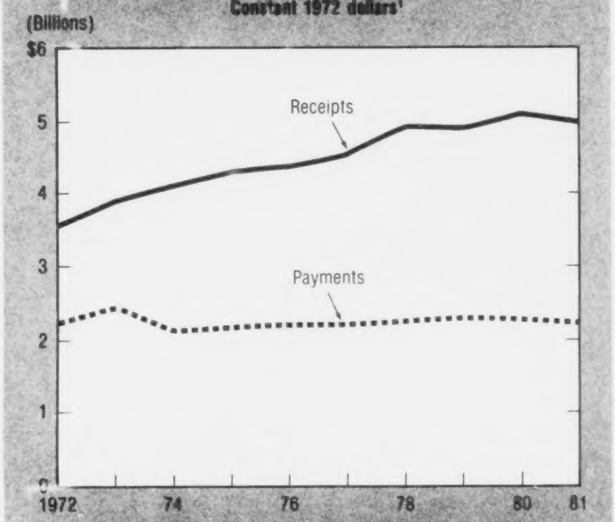
The discussion above has concentrated on the ability of U.S. firms to profit from the international diffusion of their technologies. Indicators of three major channels for the diffusion of technology—direct investment, licensing agreements, and trade in high-technology products—show that U.S. firms have recently experienced less success in their efforts to export technology than they had in previous years. The U.S. direct investment position, both exports and the trade surplus in high-technology products, and receipts of royalties and fees have all fallen. Thus, whether because of an unfavorable economic climate, loss of technological competitiveness, or other reasons, U.S. firms have had less opportunity to spread their R&D investments

Figure 1-12
U.S. receipts and payments of royalties and fees associated with unaffiliated foreign residents



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
See appendix table 1-16. Science Indicators—1985

Figure 1-13
Total receipts and payments of royalties and fees: United States, Japan, West Germany, France, and United Kingdom



¹The GNP or GDP implicit price deflators are used to convert the data from national currency to constant 1972 prices. The 1972 purchasing power parities are then applied to convert to U.S. dollars.

See appendix table 1-17. Science Indicators—1985

across international operations than they once had. Against this background, the success of U.S. exporters at maintaining their share of shrinking international markets for high-technology products, in spite of unfavorable movements in exchange rates, suggests that the contraction of the flow of U.S. technology to foreign markets does not reflect technological weakness. U.S. products continue to sell well, compared to the products of the other advanced industrialized countries.

The importance of indicators of the international diffusion of technology extends beyond their use in analyzing the attractiveness of the international economy to U.S. firms, or the technological competitiveness of U.S. firms. First, it has been suggested that the channel for diffusion will be partly based on the age of the technology.[15] When a technology is young and changing rapidly, the innovator may choose to keep production close to the laboratory, where fine-tuning adjustments can be made. After a certain period, production becomes standardized, and the firm can set up facilities overseas, in the form of direct investment. Profits from the initial exporting phase help to finance the overseas expansion.

Second, the form of the diffusion may have implications for the distribution of future benefits from the use of the new technology. Exports of products which embody new technologies employ labor in the United States, while both direct investment and licensing involve the transfer of production overseas. More than either direct investment or exports, the licensing of technology may encourage rapid competitive imitation of the technology or the establishment of foreign rivals. Finally, expansion through direct investment may permit the firm the greatest control over the expansion of the market for the new technology.[16]

In fact, evidence suggests that firms prefer either direct investment or exports to licensing as channels for marketing their technological advantages overseas.[17] Licensing is chosen when the technology to be transferred is peripheral to the firm's main line of business, when there are unusual risks or problems associated with direct investment, when the invention has a short expected economic life, or when the recipient country discourages or restricts the other channels for transfer.

Conversely, both firms and governments may positively prefer to purchase disembodied technology, through licenses and other agreements, rather than to receive it along with the presence of the innovating multinational, or to import it embodied in products which were produced elsewhere. While licenses are generally encouraged, imports of high-technology products may be discouraged, both because they compete with domestic firms and because they employ labor abroad rather than at home. The attitudes that the different countries take toward foreign technology may therefore influence how a country trades technology. A country which places its own firms at the center of its international trade and technology policies will encourage the acquisition of foreign technology through patent licensing and other agreements, rather than through the purchase of high-technology products. When its firms seek to sell their own technologies abroad, they will emphasize product exports, and sell relatively few patent licenses.

The approach each country takes to the different channels for the international diffusion of technology can be summarized by the ratios of royalty and fee receipts to payments, and of high-technology exports to imports. When countries encourage the acquisition of disembodied technology, through patent licensing and other arrangements, but promote exports of high-technology products in preference to transfers through licensing agreements, these ratios will be relatively low. In figure 1-14, both ratios for West Germany and Japan are less than one, demonstrating a degree of technological competitiveness in trade, as exports of high-technology products exceed imports, which is not accompanied by a surplus of royalty and fee receipts over payments. With high-technology exports over four times as great as imports, Japan is highly competitive in trade. Nonetheless, Japan sells relatively few licenses, apparently choosing other channels for the diffusion abroad of Japanese technology. In contrast, U.S. technological strength is demonstrated in both diffusion channels, experiencing large and growing surpluses of license receipts over payments, and maintaining a trade surplus in high-technology products. The United Kingdom is the only other country here which has received royalty fees in excess of payments,

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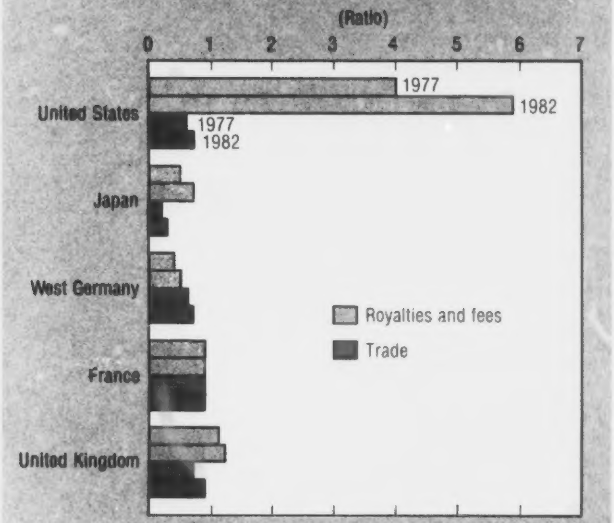
[15] Two seminal works on the theory of the product cycle are Vernon (1966) and Hufbauer (1966).

[16] See Teece (1983).

[17] See Mansfield, et al. (1979).

Figure 1-14
High technology import-export and royalty and fee receipt-payment ratios for selected countries



[1]Royalty and fee ratios for Japan, West Germany, and the United Kingdom are for 1981.

See appendix tables 1-14, 1-17.

Science Indicators—1985

while France has experienced relatively small surpluses in high-technology products.

Between 1977 and 1982, both measures of technological openness have increased for most countries (although France experienced a slight decrease in its royalty-and-fee ratio). In spite of difficult economic circumstances, all five countries were open to increases in the levels of high-technology imports, relative to exports, and generally relied less on purchases of foreign disembodied technology. Such a trend, if it continues, would indicate a higher overall volume of trade in high-technology products between these countries, accompanied by stronger domestic commercial S/T endeavors. If firms can choose their preferred channel of technology transfer—be it direct investment, licensing or trade—the profits for successful innovation will be higher. This would encourage greater R&D efforts, while the open international system permits specialization and exchange, instead of duplication of activity in the different countries.

International Patterns of Specialization in Commercial Science and Technology

One outcome of the international diffusion of commercial technology is a pattern of specialization where different countries concentrate upon different products, and where, more importantly, there is a division of labor in the R&D which goes into the development of new technologies. The alternative, where the firms in different countries continually seek the lead in all emerging technologies, is likely to produce duplication of R&D efforts and potential political tension among the countries concerned. This section investigates the available evidence for emergent divisions of labor and specialization in commercial technology.

Several aspects of specialization in commercial technology can be examined. First, international division of labor in research and development will result in different countries emphasizing R&D efforts in different industries. The areas of emphasis and de-emphasis for these countries can be examined. Second, S/T activities in the different industries may be concentrated in a few countries which emphasize the industry. The degree of concentration of S/T activities of different industries helps to describe the existence and strength of an international division of labor in commercial science and technology.

In 1979, 88 percent of the R&D expenditures by businesses in the market economies of the OECD were spent in the United States, Japan, West Germany, France, and the United Kingdom.[18] A discussion of the international structure of commercial technology is thus largely an analysis of activities in the United States and in the four other large countries which have received most of the attention thus far in this chapter. Furthermore, the bulk of industrial R&D expenditures in these countries was made in a few industries. In 1981, 70 percent of the R&D expenditures by businesses in the five countries as a group were concentrated in six industries: the Electric and Electronic Machinery and Equipment Group, Chemicals, Aerospace, Motor Vehicles, Office Machinery and Computers, and Instruments.

National Emphasis in Commercial Science and Technology. The six industrial groups identified here (see table 1-3) receive the bulk of both private and public R&D expenditure. Therefore, they are the areas where technological efforts and national science policies are most likely to come into contact. The extent to which countries emphasize the same industries can be shown by examining relative emphasis indices for industrial R&D expenditures. Table 1-3 shows each country's share of the five-country R&D expenditure total in a particular industry, relative to that country's share of R&D expenditures in all industries. A positive index indicates relative emphasis in the industry; a negative index indicates de-emphasis.

The United States has emphasized R&D in the Aerospace, Instrument, and Office Machinery and Computer industries. In 1981, U.S. industry performed about 84 percent of the privately financed R&D in the five countries in these three industries, but only 61 percent of privately financed R&D in all industries. Both Britain and France placed a relatively greater emphasis on Aerospace than did Japan, although the distinction was less sharp in 1981 than in 1975. Japan, France, and West Germany placed a greater emphasis on R&D in the Electrical group than did the United States or the United Kingdom. Specialization in this industry as well as in the Aerospace and Instrument industries has increased during the past 6 years; however, it has fallen in the Chemical, Computer, and Office Machine industries.

There is no clear trend toward, or away from, specialization in R&D expenditures in the six industries examined here. However, two points can be made. First, there is

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[18] See OECD (1984a), p. 51.

Table 1-3. Relative emphasis[1] of R&D expenditures in the business sector by country, for selected industries: 1975 and 1981

Industry	Year	United States[2]	West Germany	Japan	United Kingdom	France
Electrical group	1975	−0.07	0.28	0.03	−0.06	0.11
	1981	−0.11	0.22	0.26	−0.11	0.17
Chemicals	1975	−0.35	1.51	0.30	0.03	−0.12
	1981	−0.23	1.26	NA	0.39	0.05
Aerospace	1975	0.29	−0.50	−1.00	0.27	0.07
	1981	0.42	−0.75	−0.99	−0.11	−0.21
Motor vehicles	1975	−0.04	0.11	0.23	−0.30	0.02
	1981	−0.08	0.25	0.18	−0.32	0.17
Instruments	1975	0.33	−0.44	−0.38	−0.52	−0.64
	1981	0.34	−0.67	−0.41	−0.67	−0.81
Office machines ..... and computers	1975	0.42	NA	−0.70	−0.38	−0.11
	1981	0.38	NA	−0.58	−0.26	−0.43

[1] The relative emphases index is calculated by dividing a country's share of R&D expenditures in an industry by its share of all R&D expenditures in the business sector, then subtracting 1. Negative values indicate relative de-emphasis; positive values show emphasis in the industry's technology.

[2] U.S. data for 1975 are total business sector expenditures, and privately-financed expenditures are used for 1981.

See appendix table 1-18.

Science Indicators—1985

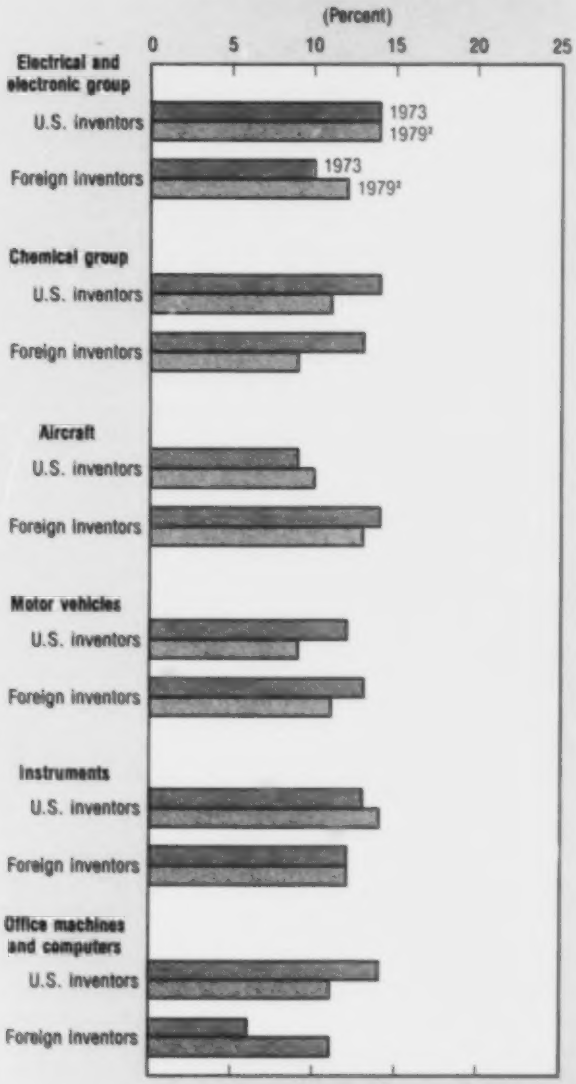
increasing specialization in three of the four industries in which U.S. firms spend a higher amount on R&D than do firms from the other countries. The exception to this trend is the Office Machines and Computers group, which has been the subject of intense competition in recent years. Second, in the industries in which specialization has increased, R&D expenditures have been higher relative to sales than in the industries experiencing decreasing concentration. Once again, the Machines and Equipment group is the exception.

Data on industrial R&D expenditures provide a useful overview of the international structure of commercial S/T. A more detailed analysis is possible through the use of data on patenting in particular technologies. Furthermore, patent-based data indicate the output of new inventions from the system, complementing the data on the resources devoted to research and development.

When patent applications are submitted to the United States Patent Office, they are examined by that Office's technical staff, who investigate the utility and originality of the applicant's invention. In the patent document which is finally issued, these examiners make references to the relevant "prior art." The patents covering important inventions have been found to be cited heavily in subsequent documents. This approach has been extended to provide an indication of the quality of the efforts of U.S. and foreign inventors in the six industries described above. Figure 1-15 shows that U.S. inventors are particularly strong, compared to their foreign counterparts, in the Office Machine and Computer industry; in addition to receiving 64 percent of the patents issued overall in the field in 1978, U.S. inventors were responsible for 74 percent of the patents in the most highly cited decile in that product field. On the other hand, since the early 1970's the technical quality of patents granted to U.S. inventors in the Aircraft and Motor Vehicle areas has fallen when compared to the performance of foreign inventors.

Table 1-4 shows the relative emphasis that different countries place on patenting in several technologies. The technologies, chosen to represent a range of areas where inventors are now active, include two older technologies (Steel and Iron, and Internal Combustion Engines), three well-established high-technology areas (Drugs, Integrated Circuits, and Telecommunications), and three young technologies (Robotics, Lasers, and Microbiology-Enzymology). In this sample of technologies, patterns of relative emphasis and specialization do emerge. Each country places a relatively high emphasis on one or two technologies; further, it places a greater relative emphasis on those technologies than the other countries. Similarly, where a country places its lowest emphasis, it usually has the lowest emphasis index of any of the countries. Only the United States does not show a strong emphasis in any of the technologies. However, the United States is the largest and richest of the countries studied here, and is therefore able to support efforts in a wider range of technologies. Instead of the six high-technology areas, U.S. inventors placed moderate emphasis on four, and de-emphasized only Robotics. U.S. inventors have placed little emphasis on patenting in the low-technology areas, particularly in Steel and Iron. In three of the four fields which U.S. inventors emphasized, Japanese inventors were even more active, suggesting con-

Figure 1-15
Percent of U.S. patents in selected product groups, granted to U.S. and foreign inventors, which are highly cited.[1]



[1] Patents are ranked within each product field by the number of citations they receive from subsequent U.S. patents granted during the period 1973-82. A citation threshold was determined separately for each product field and time period. Only those patents above this threshold were considered "highly cited."

[2] Patents appearing in the most recent years would not have had time to accumulate citations. Therefore, the most recent year for which full patent citation data are feasible is 1979.

SOURCE: Computer Horizons, Inc., unpublished data

Science Indicators—1985

tinuing competition between Japan and the United States in the fields which these countries emphasize.

The shifts shown above in the fields of specialization for different countries may reflect the rapidity of technological advance, which does not permit countries to develop persistent advantages, and the influence of scientific advances on commercial S/T. The rapid international diffusion of fundamental science, and its incorporation into commercial technology, may continually set countries on a similar basis for the exploitation of new commercial technology.

THE INTERACTIONS OF INTERNATIONAL SCIENCE AND ENGINEERING

The preceding section discussed the development and commercialization of the products and processes which embody new technologies. The pursuit and application of technological change form an important part of the S/T system, providing one of the system's most concrete benefits to society. But neither science nor technological change can be isolated from the system of which they are a part; the volume and quality of the stream of scientific discoveries deserve the same careful attention that technology's transformation of ideas into products and processes has received. The benefits of technology are unattainable without the initial advances of science; this section therefore considers scientific discoveries, which permit and nourish technological change.

Both science and technology are international activities—what happens in one country affects events in other countries. However, the nature of the international interactions is very different in the two activities. Scientists and engineers are equally sensitive to the potential benefits to their research from the criticism and advice of their colleagues abroad, and therefore encourage international diffusion of their research results. In technology, the dictates of competition frequently make such sharing of information undesirable. The international interactions of science have therefore involved a greater degree of cooperation than has the international competition in technology. This section discusses the contributions that different countries make to the common pool of knowledge, and the access of American and other scientists and engineers to that pool.

Support for Research

The principal aim of research is to "gain a fuller scientific knowledge or understanding of the subject studied."[19] The aim of this section is to analyze the support for the new knowledge upon which all scientists and engineers draw. It is therefore useful to distinguish between R&D efforts whose results will in general be made public, and those whose results will be controlled by the R&D performer. The analysis of expenditures for new public knowledge therefore excludes expenditures for "applied research" and "development" in businesses, and for "development" in the government sector, but includes a small amount of "development" in colleges, universities, and nonprofit institutions.[20]

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[19] See NSF (1984b) p. 71.

[20] This estimate of expenditures for new public knowledge probably overstates such expenditures for the United States, as a substantial part of the basic and applied research which the Department of Defense performs internally must remain secret. In 1981, the Department of Defense accounted for about 25 percent of the Federal obligations for intramural research, or about 7 percent of the total research expenditures for the United States. See NSF (1983), p. 41.

Table 1-4. Relative emphasis[1] for patenting in major patent systems by country, for selected technologies: 1980-82

Technology group	United States	West Germany	Japan	United Kingdom	France
Robotics	-0.41	-0.20	-0.35	-0.37	0.78
Lasers	0.32	-0.43	0.81	-0.22	0.06
Microbiology-enzymology	0.12	-0.28	0.68	0.00	-0.26
Drugs	0.26	-0.19	-0.02	0.93	0.28
Integrated circuits	0.17	-0.44	1.35	-0.59	-0.77
Telecommunications	-0.02	-0.13	0.80	-0.24	0.06
Internal combustion engines	-0.08	0.69	-0.10	0.23	0.35
Steel and iron	-0.38	-0.42	0.95	-0.60	-0.37

[1] This index is calculated by dividing each country's share of all patents taken out in a technology in 26 major patent systems by the country's share of all patents issued by those patent systems, minus one. An index of 0 indicates no relative emphasis or de-emphasis; positive numbers indicate relative emphasis, negative numbers indicate relative de-emphasis.

See appendix table 1-20.

Science Indicators—1985

The pursuit of new public knowledge occupied a significant share of the national R&D expenditures in the main R&D-performing countries. In West Germany, Japan, and France, about one-third of domestic expenditures on R&D in 1981 were spent in the sectors and activities identified above with this effort. The share of U.S. expenditures devoted to this pursuit was somewhat lower, about one-fifth, but the U.S. science and technology endeavor is so large that it represents 44 percent of the total of these expenditures in the four countries. There were thus substantial efforts by all four countries to contribute to the new scientific knowledge which underpins technological progress. (See appendix table 1-21.)

The fields which the different countries emphasize vary considerably. Japan reports slightly more engineering research than does the United States, although it spends less than two-thirds as much as the United States in all fields combined. The United States effort in the natural sciences is more than double that of Japan and West Germany combined, but in the agricultural sciences, U.S. expenditures approximately equal those of Japan and West Germany combined. The data thus suggest Japanese strength in engineering and in the medical and social sciences, and German strength in the natural sciences. These may be areas where U.S. scientists and engineers can usefully collaborate with their foreign colleagues; they may also be areas of future technological strength for these countries.

International Study and Academic Exchange

In any international system, the channels which link activities in different countries take on great importance. Trade in products, and in patent licenses and flows of direct investment, receive the attention of policymakers as channels of international transfer of technology. It is less easy to identify the channels through which scientific knowledge is diffused internationally. In part, this is a consequence of the public-good nature of this knowledge; the cost of its transfer is low relative to the cost of its production, and there is generally no discrete transaction to be measured, as there is in the sale of technology.

Fortunately, the links between science and engineering in different countries are pervasive, and one can identify, and possibly measure, many activities whose purpose is to facilitate the communication of ideas from one country to another. These activities are examined below. First, there are visits by scholars from one country to another. These may be students learning from another country's scientists, or more senior scholars carrying their results abroad, seeking the advice and criticism of their foreign colleagues. Second, there are publications in, and use of, the international scientific literature. Finally, there are the explicitly cooperative activities, where scientists from different countries work together and share the results of their work.

Foreign Students. Given the leading position of U.S. science and technology, it is natural that the United States hosts large numbers of foreign students who wish to study here. Many of these come from the less developed or newly industrialized countries seeking advanced courses that may not be available at home. Students come from the other industrial countries in smaller numbers since these students have alternative opportunities closer to home. The United States has long attracted students from many parts of the world. In 1978, students in the United States represented over one-third of the foreign students studying in the 20 largest host countries, more than twice as many as studied in France, the next largest host country.[21] Other countries hosting many foreign students are the Soviet Union, the United Kingdom, and West Germany. However, in relative terms, foreign students play a smaller role in the United States than they do in several other countries. Two percent of U.S. students were non-resident foreigners, as opposed to 11 percent in France, 8 percent in the United Kingdom, and 5 percent in West Germany, but only 1 percent in the Soviet Union and in Japan.

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[21] See Institute of International Education (1984).

Figure 1-16 shows the trends in the numbers of students in the United States from selected countries. Although S/E students cannot be shown separately for these countries, over 60 percent of the foreign students who have declared majors are in the sciences and engineering. This high level of interest in these fields has been stable since the early 1960's. Therefore, these data provide useful indications of the numbers of S/E students in the United States from different countries.

Students from the People's Republic of China are entering the United States in increasing numbers. In 1982-83 over 6,000 mainland Chinese students studied in the United States; during each year prior to 1979, fewer than 325 students from the People's Republic of China enrolled in U.S. colleges and universities. Taiwan, Canada, and Japan continue to send large numbers of students to the United States, demonstrating the close links between the United States and those countries. The Soviet Union and other Eastern European countries have never sent large numbers of students to the United States. However, there were more students in the United States from that region during the 1982-83 school year than in any other year; in that year, over half the Eastern European students in the United States were from Poland.

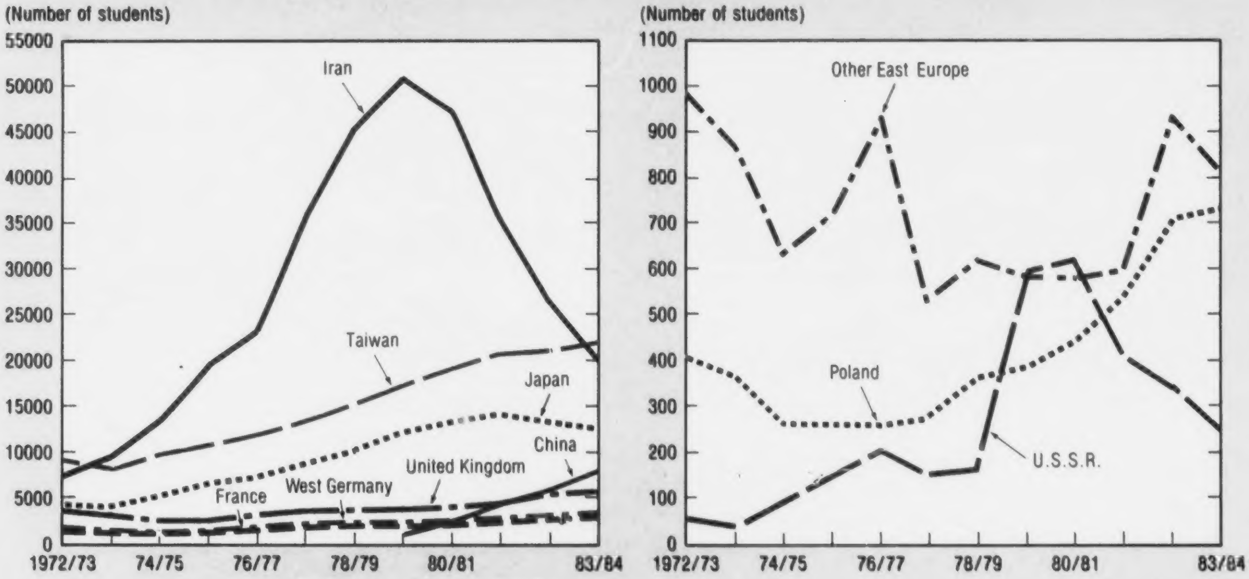
Foreign graduate students and doctorate recipients are particularly important to U.S. science and technology: they make a greater contribution to research during their stays in the United States than do undergraduates, and they return to more advanced positions in their home countries' S/T systems.

For a number of years, the proportion of foreign graduate students and doctorate recipients in science and engineering in the United States has increased. Figure 1-17 shows the share of doctorates awarded to foreign citizens in S/E disciplines. Since 1981, more than half of the doctorates awarded by U.S. universities in engineering were given to foreign citizens. Foreign students also took large and increasing shares of the doctorates awarded in physics and in mathematics. The increasing share of doctorates awarded to foreign students is driven by two factors. First, the number of U.S. students receiving the Ph.D. has fallen. Second, the number of foreign recipients has increased, particularly in engineering, where the number of foreign residents receiving Ph.D.'s grew by 125 percent between 1972 and 1983. (See appendix table 1-23.)

Most foreign recipients of Ph.D.'s from U.S. universities plan to leave the United States following completion of their doctorates. (See figure 1-18.) However, the proportion of foreign residents with commitments for plans for work in the United States following completion of the Ph.D. has increased in recent years, so that in 1983 almost half of the foreign S/E Ph.D. recipients with firm plans expected to remain in the United States. Employment

Figure 1-16

Non-immigrant students in the United States, by nationality

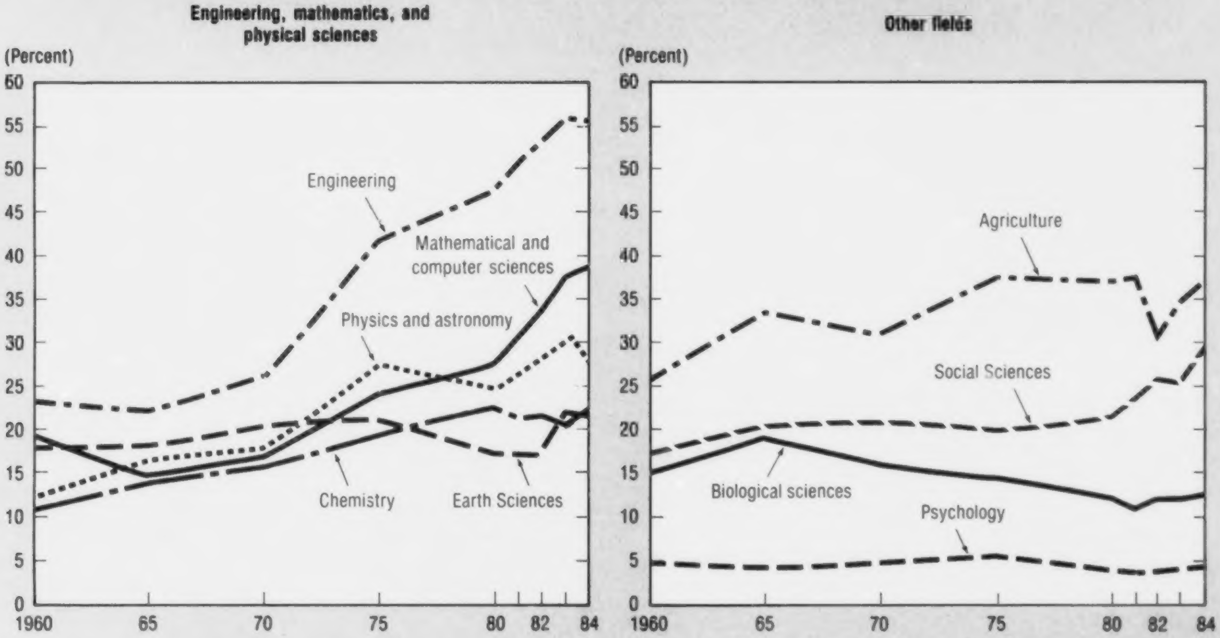


See appendix table 1-22.

Science Indicators—1985

Figure 1-17

Doctoral degrees awarded to foreign students as a percent of all doctoral degrees from U.S. universities, by field



See appendix table 1-23.

Science Indicators—1985

opportunities for these foreign scientists and engineers were particularly abundant in engineering and in the computer sciences, where shortages of U.S. personnel have been reported.[22] A high proportion of foreign Ph.D. recipients in mathematics have found employment in the U.S. colleges and universities, perhaps reflecting the movement of U.S. mathematicians into the related computer science areas. In fields where employment prospects are less auspicious, such as the life sciences, social sciences, and earth, environmental and marine sciences, almost all those foreigners with positions in the United States after receiving their doctorates pursue postdoctoral studies. The post-graduation plans of foreign Ph.D. recipients thus seem strongly influenced by the state of the U.S. labor markets; foreign Ph.D. recipients seem to form a reserve labor pool which helps to alleviate shortages as they arise in the U.S. domestic markets.

Except in engineering, the high shares of foreign residents in the doctorate-receiving population is matched by even higher shares in the graduate student population as a whole.[23] In 1982, they represented 43 percent of the graduate students in engineering at U.S. doctorate-granting institutions, about the same as in 1980. The lower share of foreign residents in the total student population than in the doctorate-receiving population in engineering reflects the large number of American engineering students who leave the university after receiving the master's degree. In other more academic fields, where the master's is not the final degree obtained, the share of foreign students matches the share of foreign doctorate recipients much more closely.

International Scientific Exchange. Scientists and engineers also engage in professional travel after the completion of their studies. Young scholars may travel for postdoctoral fellowships, while researchers of all ages participate in academic conferences, take temporary appointments overseas during sabbaticals, and otherwise participate in the international flow of scientific knowledge.

In the formative years of American science, postdoctoral study abroad was an important career step for young U.S. scholars. They worked in leading laboratories abroad, particularly in Europe, and brought back both knowledge of important work outside the United States, and formed lifelong relationships with their peers overseas.[24]

The number of S/E doctorate recipients with firm commitments for postdoctoral study abroad[25] has fallen sharply

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[22] See NSF (forthcoming).

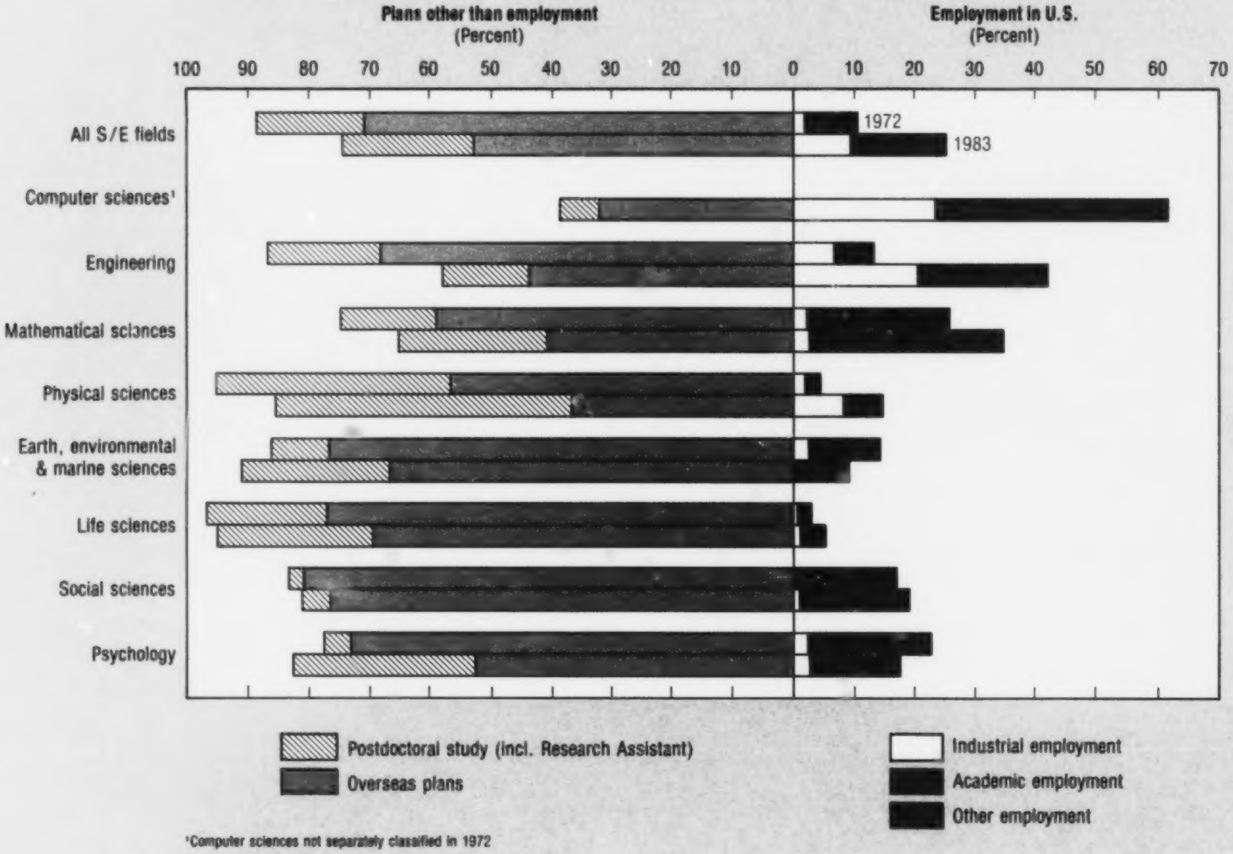
[23] See NSF (1984a), pp. 99-100.

[24] See Zinberg (1980).

[25] The data on postdoctoral study abroad count only Ph.D. recipients with confirmed positions abroad at the time of the survey, which is filled out when the degree is awarded (usually in the spring). Other postdoctoral study plans are revised or finalized after the questionnaire is returned. Therefore, these data can only be treated as approximate indicators of the magnitude of doctoral study abroad. Furthermore, although many scientists may take several postdoctoral appointments in the years after they receive their degrees, some of which take place overseas, only the first postdoctoral appointment is counted in these data.

Figure 1-18

Postdoctoral plans of foreign, non-resident recipients of Ph.D.'s from U.S. universities, by field of science



¹Computer sciences not separately classified in 1972

See appendix table 1-24.

Science Indicators—1985

since the early 1970's, when 2 percent of all U.S. doctorate recipients traveled abroad for postdoctoral studies. Figure 1-19 shows that this decrease was sharpest in physics and in chemistry, which together had accounted for half of the postdoctoral appointments abroad in 1971. Overall, between 1971 and 1982 the number of American citizens and permanent residents with firm commitments for postdoctoral study abroad fell by 44 percent. During the period when study abroad by new U.S. science and engineering Ph.D. recipients decreased, major overseas research facilities increased and made important contributions to world science. Advanced facilities such as those at CERN, the European High Energy Physics Center in Switzerland, might be expected to attract young American scientists. However, while some foreign facilities may continue to draw substantial numbers of young U.S. scientists, in general international postdoctoral experience seems less attractive to U.S. scientists than it once was.

American researchers have noted the growing strength of foreign science by citing it in their publications. In articles published by American scientists in world-class physics journals in 1982, 56 percent of the citations were to work written abroad, versus 48 percent in 1973. (See figure 1-20.) Sixty percent of the citations in chemistry articles by Americans in 1982 were to foreign work.[26] These citations demonstrate awareness in the United States of important work in progress overseas. However, researchers at the beginning of their careers have apparently either lacked the same opportunities to participate in this work first-hand that their more senior colleagues had, or have been unwilling to pursue opportunities abroad, at a time when foreign science is stronger than it was previously.

No good data exist to measure the travel habits of American S/E's beyond the data discussed on the postdoctoral study abroad by new Ph.D. recipients. One can, however, identify academic visitors among the foreigners visiting the United States. The U.S. Department of State issues the J-class visa to non-immigrant vistors who are sponsored by academic institutions in the United States. Few of these

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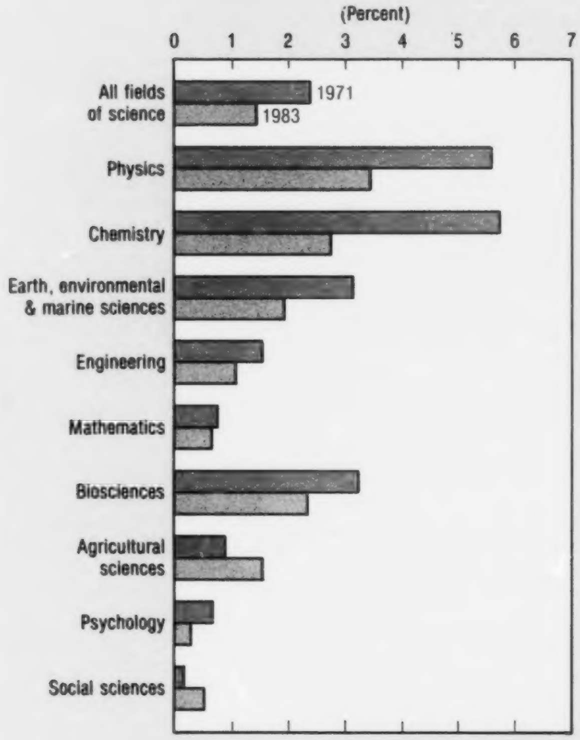
[26] See Computer Horizons, Inc. (1984).

Figure 1-19

Postdoctoral study abroad by U.S. Ph.D.'s[1]



[1] Including U.S. citizens and foreign citizens with permanent resident visas.

See appendix table 1-25. Science Indicators—1985

are students, since students generally receive the F-visa. Academic exchange vistors include postdoctoral fellows, visiting professors, and conference participants. In contrast to the foreign student population, a large percentage of academic exchange visitors come from other advanced countries. In 1983, 29 percent came from just Japan, Germany, the United Kingdom, and France (see figure 1-21), while only 8 percent of the students came from those countries.[27] These data suffer from the same limitation as the data on international students shown in figure 1-17; no distinction is made among the sciences and engineering, humanities, and other subjects. However, unless the share of scientists and engineers among all academic visitors is falling, which seems unlikely, the data do describe a rising trend in the number of foreign S/E's participating in academic visits to the United States.

The number of J-visas issued to all nationalities increased by 35 percent between 1978 and 1983.[28] This increase has been most noticeable for visitors from West Germany and from Japan, who received, respectively, 63 percent and 46 percent more exchange visitor visas in 1983 than they did in 1978. This increase took place even though the dollar greatly increased in value, relative to other currencies, making such visits particularly expensive for foreign S/E's. This gives further support to the positive evaluation of U.S. science and technology by foreign scholars.

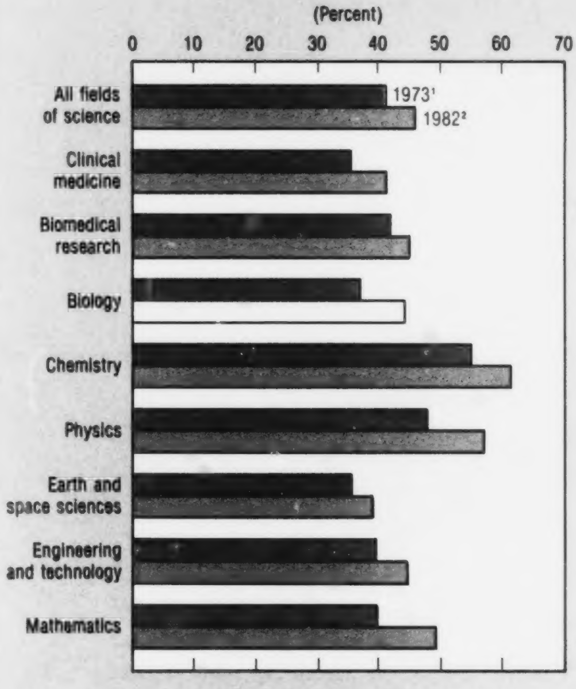
International Cooperation and Communication in Science

The exchanges of students and S/E's described in the previous section contribute to the more rapid diffusion of science and technology. The open scientific literature has been the primary channel of this diffusion, both within countries and between countries. Publication is important to researchers, because as well as demonstrating the fruits of their work, it opens up their methods and results to criticism and suggestions by their peers.

The links between research in different countries are enhanced when an article by a researcher in one country appears in a journal published in another country. Successful

Figure 1-20

References in U.S. articles to articles from other countries, by field



[1] Citations in 1973 articles published in more than 2100 journals covered by the Corporate Tapes of the 1973 *Science Citations Index* of the Institute for Scientific Information.

[2] Citations in 1982 articles published in the more than 3500 journals covered by the Corporate Tapes of the 1981 *Science Citations Index* of the Institute for Scientific Information.

See appendix table 1-28. Science Indicators—1985

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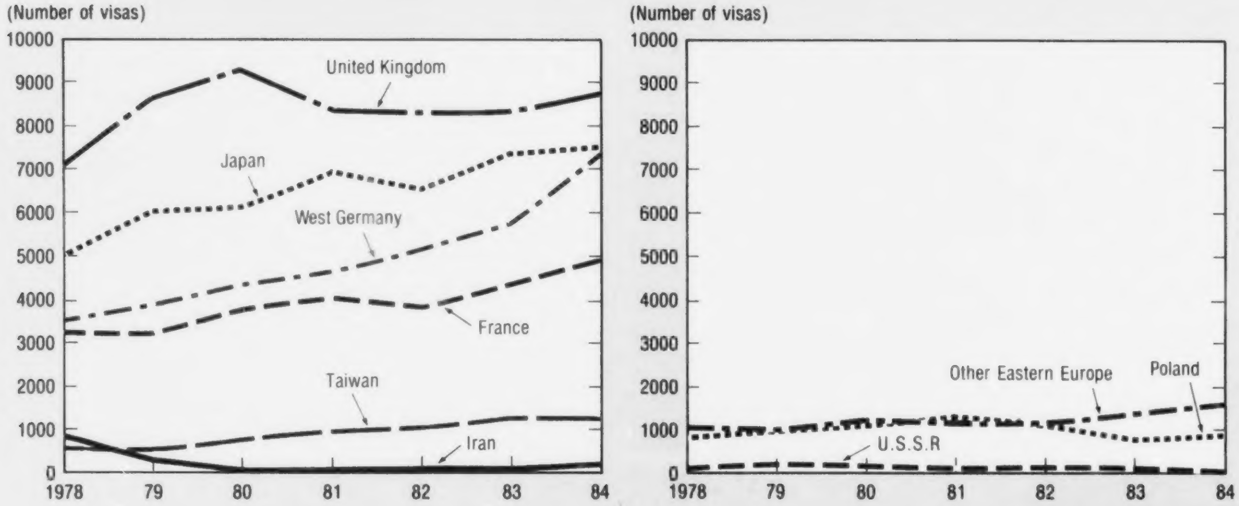
[27] See Institute of International Education (1984).

[28] See appendix table 1-28.

Figure 1-21

U.S. academic exchange visas issued by nationality of recipient



See appendix table 1-26.

Science Indicators—1985

efforts at international communication in science are demonstrated when authors in one country cite the work of foreign researchers in their articles. International citation indicates both the existence of ties between the scientists, and the importance of foreign advances to a country's S/T endeavor. Finally, the most concrete form of international scientific cooperation, where scientists and engineers from different countries work together on a project, will often result in articles which are co-authored by the participating scientists.

The world's leading scientific journals provide an active international forum for new knowledge. In 1982, 42 percent of the articles published in world-class science journals covered by the Science Citation Index (SCI) appeared in journals published outside the author's home country.[29]

U.S. authors were active participants in this interchange; over 22,000 U.S. articles, or 21 percent of the covered output of U.S. science, were published outside the United States. About one-third of the articles published in the leading American journals had foreign authors. Foreign authors published extensively in the U.S. chemistry and physics journals, writing 48 percent and 44 percent, respectively, of the articles published in these journals in 1982. (See figure 1-22.) In contrast, foreign scientists only contributed one quarter of the articles published in American biology clinical medicine journals—a pattern which is followed in the literature of other countries as well.

Journals which report basic science generally present more foreign work than do those which concentrate on applications. This may reflect different practical problems and emphases in different countries. Over the past decade, there has been a tendency in almost all fields and countries for the number of articles published outside the author's home country to increase.

If active cooperation between senior scientists does take place, it will result in research articles co-authored by researchers from different countries. Figure 1-23 shows that in most fields of science and engineering international co-authorship[30] has increased steadily since 1973. Throughout the period, mathematics has been the discipline experiencing the greatest degree of international cooperation, while clinical medicine seems to be largely nationally-based. Physics has increasingly been the focus of international research activity, due perhaps to the cost of high-energy physics research facilities, and to the need for team work in this complex research area. In recent years, the role of multinational research work has diminished in biology.

The European countries have emphasized international research more than have the United States and Japan. (See figure 1-24.) This is not surprising; geographic and linguistic distance separates Japanese S/E's from their foreign peers. While the United States has such a sufficiently

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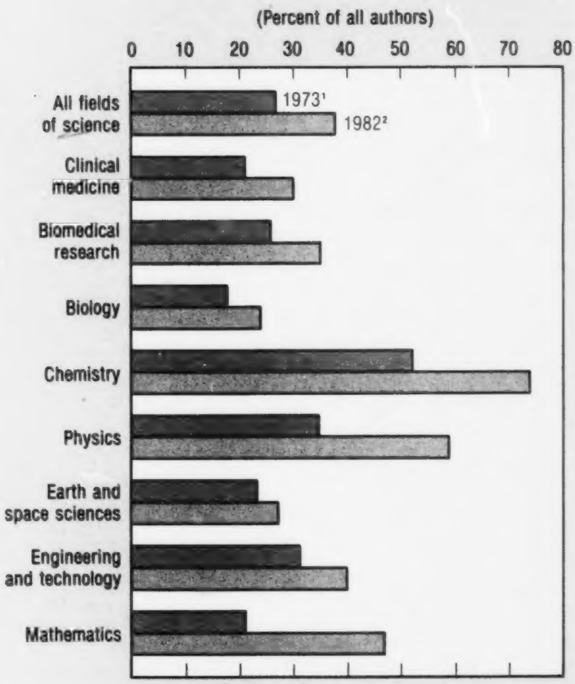
[29] "Home country" is based on the institution of the author. See appendix table 1-28.

[30] Institutional co-authorship—the publication of articles with authors from different institutions—reflects in part the requirements of particular fields of science and the practices of research institutions in different countries. These practices and requirements may change over time. To account for the varying underlying tendency to write articles co-operatively in different countries, fields, and years, the international co-authorship index normalizes the number of articles with authors from more than one country by dividing by the number of all articles with authors from different institutions.

Figure 1-22

Articles in U.S. journals which have foreign authors, by field of science



[1] Articles published in U.S. journals covered by the Corporate Tapes of the 1973 *Science Citations Index* of the Institute for Scientific Information.

[2] Articles published in 1982 in U.S. journals covered by the Corporate Tapes of the 1981 *Science Citations Index* of the Institute for Scientific Information.

See appendix table 1-27.　　Science Indicators—1985

diverse and rich scientific system that international cooperation loses some of its appeal, European scientists find cooperation relatively easy, due to geographic proximity and language familiarity. Furthermore, in recent years, there has been an explicit sharing of facilities, through CERN and the Joint European Torus (JET), and through other joint activities, such as the research program of the European Space Agency.

From the discussion above, it is clear that formal cooperative research is not a necessary precondition of effective diffusion of knowledge. International study and postdoctoral activities and regular access to and use of the international scientific literature are important links in the international science and technology system. The form of the international diffusion of knowledge has changed, in science as in technology, reflecting the evolution of the international environment in which scientific and technological activities take place.

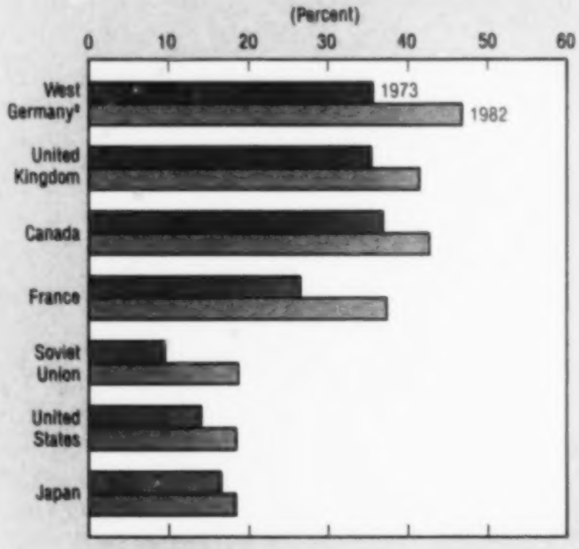
OVERVIEW

The United States continues to play a leading role in the international science and technology system. The U.S. research and development effort is greater than the combined efforts of its four largest market-economy competitors, whether measured in terms of R&D expenditures or of scientists and engineers employed in research and development. Only the Soviet Union has a larger R&D workforce than the United States. The overall strength of U.S. scientific and technological activities is observed as well in the outputs of S/T. U.S. scientists and engineers publish extensively in the world's leading research journals, while U.S. inventors take out more patents in foreign countries than do inventors from any other country. The strong performance of the U.S. science and technology endeavor has contributed to the high productivity of the U.S. economy, whose output per employed person is the highest among the five largest market economies.

The strong U.S. science and technology performance may be accounted for in part by the size of the U.S. economy. The share of U.S. gross national product which is devoted to R&D expenditures is approximately equal to the share for the other large market economies. The much larger economic base of the United States thus supports a more substantial R&D effort, in absolute terms, than the other countries can afford. The relative size of the R&D efforts of the largest market economies are also similar when measured by the proportion of R&D scientists and engineers to the total labor force.

Figure 1-23

Index of international cooperative research[1], by country



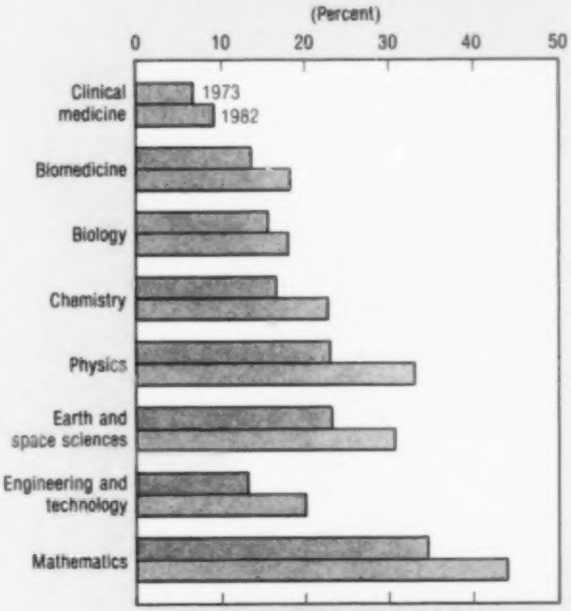
[1] Obtained by dividing the number of articles which were written by scientists and engineers from more than one country by the total number of articles jointly written by S/E's from different organizations. This index is based on articles, notes, and reviews in over 2,100 influential journals carried on the Corporate Tapes of the 1973 *Science Citation Index* of the Institute of Scientific Information. The last two years are based on over 3,500 journals in the 1981 *Science Citation Index*.

[2] When an article is authored by scientists and engineers from more than one country, that article is counted once for each country involved.

See appendix table 1-30.　　Science Indicators—1985

Figure 1-24

Index of international cooperative research[1], by field



[1] Obtained by dividing the number of articles which were written by scientists and engineers from more than one country by the total number of articles jointly written by S/E's from different organizations. This index is based on articles, notes, and reviews in over 2,100 influential journals carried on the Corporate Tapes of the 1973 *Science Citation Index* of the Institute of Scientific Information. The last two years are based on over 3,500 journals in the 1981 *Science Citation Index*.

See appendix table 1-29. Science Indicators—1985

The R&D efforts of the major industrialized market economies, while similar in relative terms, vary considerably in terms of their emphases. The United States, France, and Great Britain all devote relatively high shares of their R&D resources to defense-related activities. In contrast, for historical and cultural reasons West Germany and Japan perform little defense-related R&D, and support relatively larger civilian R&D efforts than the United States, France, and Great Britain.

The Soviet Union appears to have the largest R&D endeavor in the world in both absolute and relative terms. The Soviet Union is estimated to employ between 40 and 60 percent more S/E's in R&D, as a percentage of the labor force, than does the United States; it also devotes a significantly greater share of its GNP to R&D. Of course, institutional differences between the two countries may obscure the meaning of these comparisons. In particular, the Soviet activity is concentrated in research institutes attached to the Soviet production ministries. The size of the Soviet R&D effort therefore may not necessarily translate into a strong overall science and technology system. In both the United States and the other major industrialized market economies, the level of activity in science and technology has increased substantially in recent years. Since the mid-1970's the absolute number of scientists and engineers in R&D has grown at a greater rate than the entire labor force; during the same period the proportion of GNP devoted for R&D has also generally increased. The downward trend which most of these countries experienced in their R&D expenditures as a percentage of GNP during the early 1970's has been definitely reversed. Except in the United States, the relative levels of R&D expenditures are at or above their previous high points of the 1960s. Of course, all of these economies have since experienced substantial growth, so that in absolute terms, all of these countries support much larger R&D efforts than they have in the past.

Despite the continuing strength of the U.S. science and technology, the United States faces strong competition from other countries. The United States does not dominate the international science and technology system as it once did. In most fields of science, the U.S. share of publications in the leading science journals has fallen. The number of patent applications made abroad by U.S. citizens has declined, while since 1975 patent applications by Japanese inventors have increased by about 35 percent. The U.S. edge in productivity has decreased, as growth in real GNP per employed person has been much higher in other countries. The increasing strength of S/T in other countries has both advantages and disadvantages for the United States. Certainly reduced technological dominance hurts the competitiveness of U.S. firms. On the other hand, U.S. science can build upon research findings from abroad, consumers in the United States benefit from less expensive and higher-quality imported goods, and the development of defense-related technology in friendly countries adds to the security of the Nation and its allies.

The industrialized market economies do not pursue science and technology in isolation from each other. The volume and channels of transfers of scientific and technological developments between countries affect the health of the S/T endeavor in the United States. The development of industrial technology depends in part upon the existence of markets for new products and processes. U.S. firms have increasingly looked abroad for these markets, have participated in international trade in both products and patent licenses, and have set up subsidiaries overseas, to earn benefits abroad from technologies developed in the United States. International markets are more important to firms which produce high-technology products than they are to other manufacturing industries in the United States.

The ability of U.S. firms to profit from the introduction of new technologies in foreign markets influences their willingness to make the R&D investments which lead to technological advance, and thus contribute to economic growth. In recent years, the U.S. use of the three main channels for the international diffusion of technology has fallen. The surplus in trade in high-technology products has fallen since 1980, the U.S. overseas direct investment position has decreased, and receipts by United States firms of royalties and fees from technological agreements and the sale of patent licenses have leveled off. U.S. exporters of high-technology products have operated under difficult conditions in recent years. In particular, the strength of the dollar in international currency markets has made U.S. goods more expensive in foreign markets and has favored foreign producers. Simultaneously, the policies of some foreign governments have restricted trade in goods. Nonetheless, U.S. firms have maintained their share of a shrinking international market for high-technology exports, suggesting that the reduced ability of U.S. firms to profit from the international diffusion of new technologies may be related to broader economic conditions rather than to any weakness in U.S. technology.

One result of an open international system for the diffusion of commercial technology is that different countries may specialize in different work areas of technology, resulting in an international division of labor among the various technologies. The United States has tended to emphasize R&D in the Office Machinery and Computers, Aerospace, and Instrument industries. At a more detailed level, U.S. inventors have spread their patents fairly evenly across a selection of active patent areas, while inventors from the other countries have concentrated their activities in fewer technologies.

The relationships between national S/T endeavors outside the business sector are less competitive than those described above, but no less important. The results of research in S/E fields diffuse rapidly around the world, laying the basis both for further research and for application in new technologies. Relative to the size of their national R&D efforts, other countries make larger expenditures on basic and applied research activities, which are most likely to find application outside the countries where they are performed, than the United States. Research expenditures in Japan are concentrated in engineering, while the United States performs a high percentage of the total research in the natural sciences.

Several non-commercial channels exist for the diffusion of science and technology. The United States continues to educate large numbers of foreign students in science and engineering. In mathematics, computer science, and engineering, foreign students make up a large share of the graduate student population in the United States and receive a large share of the doctorates awarded by U.S. universities. While most of these students return home, thus contributing to the international diffusion of science and technology, since 1979 increasing numbers of foreign Ph.D. recipients—particularly in the computer sciences, engineering, and mathematics—have found employment in U.S. colleges, universities and industry. In addition to contributing to scientific links between the United States and their home countries, these foreign recipients of U.S. Ph.D. degrees may form a reserve pool of scientific labor, and alleviate shortages which arise in the U.S. science and technology system.

Postdoctoral study abroad is a traditional source of international exposure for young U.S. scientists and engineers. However, in recent years the number of new U.S. S/E doctorate recipients who have pursued postdoctoral study abroad has decreased substantially. During a period when science outside the United States has advanced rapidly, the use of this channel for the transfer of knowledge back to the United States has diminished.

U.S. scientists and engineers have taken advantage of the access to foreign science which the international scientific literature affords them. About one-half of the articles which U.S. scientists cite in world-class science and engineering journals are written abroad. The explicit international cooperation which underlies the co-authorship of articles by scientists from different countries has continued to increase. International co-authorship is more common in Europe than in Japan or the United States, and occurs most frequently in mathematics and in the more fundamental fields of science. In the more applied fields, such as clinical medicine and engineering, cooperative relationships are less common, as the relationship between scientists from different countries more often resembles the competition which characterizes commercial science and technology.

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Chapter 2
Support for U.S. Research and Development

Support for U.S. Research and Development

HIGHLIGHTS

- *Continued growth observed in U.S. R&D expenditures.* National expenditures for R&D continue to grow as U.S. industry and the Federal Government increase their R&D investments. Between 1980 and 1985, national R&D expenditures grew in constant-dollar terms at an average annual rate of 5.4 percent. Increased industrial funding accounted for about 52 percent of this growth, with another 45 percent representing expanded Federal funding, primarily for defense R&D and nondefense basic research. (See pp. 31-33.)
- *R&D-to-GNP ratio continues to rise.* The ratio of national R&D expenditures to gross national product (GNP) is expected to reach 2.7 percent in 1985, up from a 25-year low of 2.2 percent in 1978. Growth in the ratio slowed in 1982 in good part because of the strong growth of the economy. (See p. 31.)
- *Strong industrial R&D spending growth is evident.* In 1980, the industrial sector emerged as the primary source of R&D support in the United States—principally in the areas of applied research and development. Industrial R&D expenditures for all sectors continued to grow at a higher rate than any other source of support. Between 1980 and 1985, industrial R&D spending expanded at an average annual rate of 5.7 percent in constant-dollar terms, compared to an estimated rate of 5.2 percent for Federal R&D expenditures and of 4.2 percent for all other sources of R&D support. Between 1984 and 1985, however, industrial R&D investment growth in constant-dollar terms was exceeded by increased Federal R&D spending with each expanding at an estimated rate of 6.8 percent and 7.4 percent, respectively. (See p. 33.)
- *Resurgence in national spending for basic research is indicated.* Between 1980 and 1985, basic research grew at a slower rate (4.5 percent) than more technologically-oriented applied research (6.0 percent) and development (5.5 percent). Estimates of growth between 1984 and 1985, however, show a renewed interest in basic research (6.0 percent), slightly less than growth for development but substantially higher than for applied research. (See pp. 36-37.)
- *Continued growth in national defense R&D observed.* National defense R&D (including the atomic energy defense activities of the Department of Energy) accounted for 68 percent of total Federal R&D budget authority for 1985, up from a recent low of 49 percent in 1979. Defense R&D is expected to increase by 23 percent between 1985 and 1986, raising R&D funds in this budget category to 73 percent of the total Federal R&D budget. (See p. 39.)
- *Federal support for nondefense basic research is expanding.* The overall level of support for Federal nondefense R&D declined from $8 billion in 1980 to $7 billion in 1985, in constant dollars, and is expected to decline slightly in 1986. This overall decline was primarily due to substantial reductions in Federal support for applied research and development. Federal basic research programs in nondefense areas have experienced strong growth. Between 1980 and 1986, basic nondefense research will have shifted from 28 percent of the total nondefense R&D budget authority to 43 percent, having grown at an average annual rate of 3.3 percent in constant-dollars. (See pp. 39-40.)
- *NSF and DOD lead Federal expansion of basic research funding.* Federal obligations for basic research reached $8 billion in 1985, 5.6 percent higher than the 1984 level in constant-dollar terms. Increased support from the National Science Foundation for basic research accounted for 25 percent of the growth, while basic research spending by the Department of Defense accounted for another 15 percent of the expansion of Federal basic research support between 1984 and 1985. (See p. 41.)
- *Federal support for agricultural R&D emphasizes biotechnology efforts.* Federal support of basic research in agriculture grew at an average annual rate of 11.4 percent between 1980 and 1985. Greater emphasis has been placed on basic research in biotechnology to speed the application of advances in molecular biology to the production of improved plant and animal life for agriculture, thus enhancing American agriculture's competitiveness in world food markets. (See pp. 44-45.)

Support for R&D in the United States continues to grow, even after an adjustment for inflation has been made. Favorable economic conditions have enabled industry and other private sources of R&D support to increase their investment in science and technology (S&T). No less important, however, are the Federal policies which have created a favorable climate for R&D investment growth. This chapter analyzes the significant trends in funding by the major contributors to the R&D system and explores the implications of those funding patterns for the status, performance, and nature of science and technology in the United States.

In the public sector, Federal R&D funding strategies have led to a significant renewal of support for basic research.[1] Strengthened Federal support in this area is based on the premise that greater sustained investment in basic scientific research will contribute to long-term economic growth, improve the quality of life, and bolster national defense.[2] This research funding strategy is designed to stimulate interaction among scientists in university, industry, and Government settings to facilitate the flow of new ideas relevant to the solution of the most challenging scientific and technical problems. Because the Federal Government is the primary source of basic research support in the United States, the impact of this strategy on the performance of basic research emerges as a topic of special interest and has been selected for special consideration in this chapter.

Another current Federal R&D policy theme is the strengthening of America's technological capabilities. Through changes in monetary policies as well as changes in tax and patent policies, the administration has sought to encourage increased private sector R&D investment and, in turn, to stimulate the rate of technological innovation.[3] At the same time, the Federal Government has restricted its direct support for applied research and development to those areas which are specific governmental responsibilities and has de-emphasized R&D support to areas in which the commercial sector has the greatest interest and expertise.

The industrial sector performs nearly three-fourths of the research and development in the United States and contributes more than half of national R&D support. The Nation's numerous firms do not act in concert, of course, with respect to R&D investment; however, strong competitive pressures both from within U.S. industry as well as from abroad have contributed to similar R&D investment strategies. An example of this in the manufacturing sector is the support of technological advance relevant to productivity gains.[4]

One specific investment strategy which has emerged in the industrial sector in recent years is increased funding of university-based research. It is hoped that greater direct investment in university research in emerging areas of special interest to the industrial sector will enhance the university's role in the development of new ideas that underlie the innovation process. An added advantage of these R&D funding arrangements is that they serve as inducements to attract more students into scientific and engineering (S/E) fields where personnel are needed to enhance commercial innovation.[5]

This chapter analyzes the forces that have shaped present R&D funding directions and the present policy environment. In the first section, national support for research and development is described with respect to the comparative growth in the sources of R&D support, changes in the location of the performance of R&D activities, and the relative emphases given to basic research and to applied research and development.

The second half of this chapter explores Federal R&D policies, focusing especially on emerging strategies for enhancing technological competitiveness through support for basic research. Federal support for research and development related to food and agriculture is also described. Other chapters explore trends in the supply of scientists and engineers and changes in the research environment in the various R&D sectors. Together, these chapters summarize the present condition of national resources for research and development.

NATIONAL EXPENDITURES FOR RESEARCH AND DEVELOPMENT

National expenditures for research and development reached a level of $107 billion in 1985. (See figure 2-1.) Half of the R&D activities in the United States in 1985 were supported by company funds, chiefly oriented toward development, and performed in industrial laboratories. (See figure 2-2.)

Although there is no known optimal level of R&D investment, trends in national support for research and development may be assessed against the background of overall economic growth. For example, national R&D expenditures are estimated to be 2.7 percent of the Gross National Product (GNP) in 1985. (See appendix table 2-2.) Thus, there has been continued growth in the R&D/GNP ratio from the low of 2.2 percent observed in 1978. The recent increases in the R&D/GNP ratio result from the steady expansion of national R&D expenditures relative to the slower average annual growth rate of the GNP. Between 1976 (the most recent low year for national constant-dollar R&D spending) and 1985, national R&D investments grew at an average annual rate of 5.0 percent (in constant 1972 dollars), while GNP grew at a yearly rate of 2.7 percent, also in constant dollars.[6]

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[1] Basic research includes studies that have as their goal a fuller knowledge of the subject, rather than any practical application. See appendix table 2-6 for a more complete definition of this research area.

[2] See, for example, Executive Office of the President (1985), and Keyworth (1984b and f, and 1985).

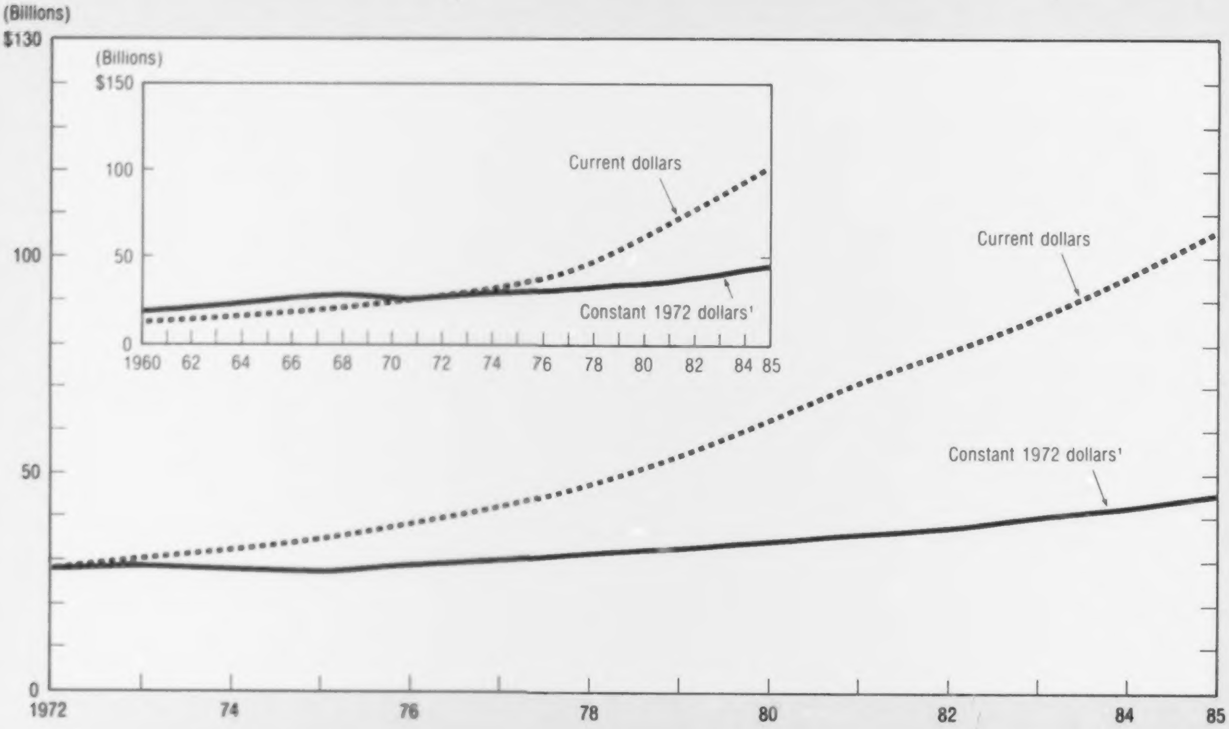
[3] See the report of the President's Commission on Industrial Competitiveness (1985) for a discussion of recommended Federal R&D policy actions designed to further enhance our technological lead. Interaction among scientists and engineers in business/industry, university, and Government is also being promoted through several indirect initiatives. The Stevenson-Wydler Technology Innovation Act of 1980 (PL 96-480), for example, promotes cooperative research through a combination of targeted program support, regulatory reforms, and other initiatives. See U.S. Department of Commerce (1984).

[4] Many factors besides changes in technology may be responsible for changes in productivity levels. For further discussion, see chapter 1, "International Science and Technology System," and chapter 4, "Industrial Science and Technology".

[5] In his keynote speech at the 1983 National Conference on the Advancement of Research, Schmitt (1984) observed: "American industry today simply cannot get enough of the people it needs in such fields as microelectronics, artificial intelligence, communications, and computer science." Stronger investment in university-based R&D is clearly one way to stimulate the production of S/E personnel for industry. See also the chapter 3, "Science and Engineering Personnel".

[6] Calculated from figures provided in appendix table 2-2.

Figure 2-1
National R&D expenditures



¹GNP implicit price deflators used to convert current dollars to constant dollars.
NOTE: Estimates are shown for 1983, 1984, and 1985.
See appendix tables 2-1 and 2-2.

Science Indicators—1985

A closer look at the year-to-year changes in the R&D/GNP ratio between 1980 and 1985 reveals that its relatively slow expansion after 1982 is related to the strong upturn of the economy even as national support for research and development continues to grow.[7]

Inflation has had a substantial impact on the purchasing power of R&D funds, as figure 2-3 shows. Between 1960 and 1967, R&D funding growth exceeded the effects of inflation; however a period of virtually no real growth in R&D funding occurred, between 1969 and 1975. After 1975, the Nation's R&D effort once again began a period of real-term growth which continued through 1985.[8] Thus, while the Nation is estimated to have spent seven times more for R&D activities in 1985 as it did in 1960, it is performing only twice the amount of R&D that it did in 1960 as a result of inflation. (See appendix table 2-3.)

One objective of America's economic policy is to improve the ability of American industry to compete on an international scale. This policy includes increased capital investment for long-term productive uses, more intense technological innovation to help industry provide competitive commercial products and processes, and increased attention to the current and future S/E workforce.[9] Research

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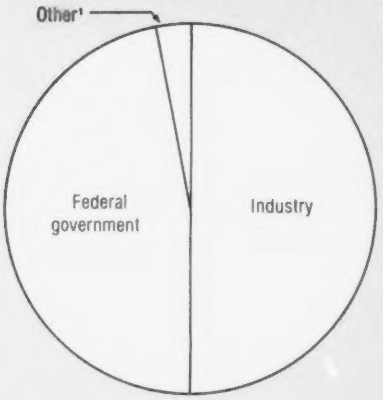
[7] In 1983 and 1984, for example, the economy was characterized by a combination of rising output, falling unemployment, and declining inflation. Industrial production rose 10.3 percent in the 13 months following the low of November, 1982, and the capacity utilization rate in manufacturing expanded from 69 to 74 percent during that period. Slightly slower growth in GNP is expected for the years 1985 through 1988. See Council of Economic Advisors (1984 and 1985).

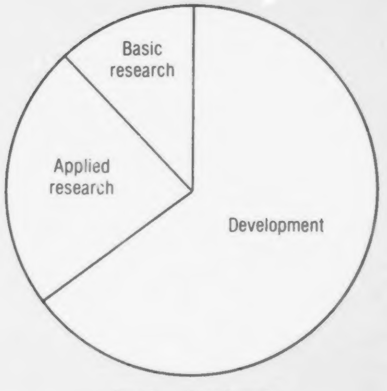
[8] See NSF (1984c), pp. 6-8, and appendix table 2-3 of this report.

[9] See, for example, Business-Higher Education Forum (1983), and Hamrin (1983). The state and stability of the U.S. economy, as well as the value of the U.S. dollar abroad, are critical factors in determining the economic success of U.S. firms. Uncertainties about future economic conditions could mitigate the benefits of other policies to help industrial competitiveness. See, for example, Newland (1982); Pechman (1983); Joint Economic Committee (1984); Task Force on High Technology Initiatives (1984); and Young (1984); President's Commission on Industrial Competitiveness (1985), and Lodge and Crum (1985).

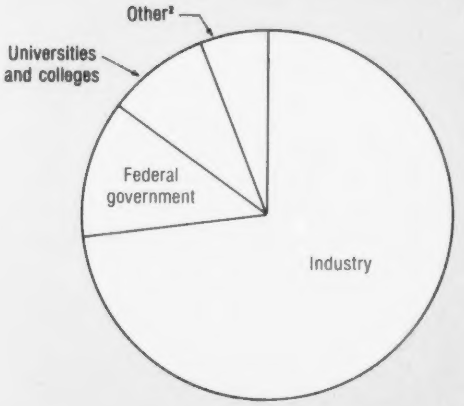
Figure 2-2
Relative distribution of national R&D expenditures by source, performer, and character of R&D: 1985



By source



By character of work



By performer

[1] Includes universities and colleges, and other non-profit institutions.

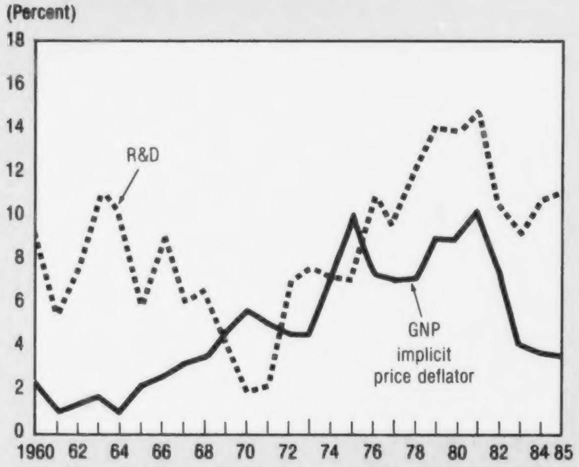
[2] Includes Federally funded research and development centers administered by universities and other non-profit institutions.

NOTE: Based on estimates for 1985.

See appendix tables 2-3, 2-5, and 2-6.

Science Indicators—1985

Figure 2-3
Annual changes in the GNP implicit price deflator and national R&D expenditures



See appendix tables 2-1 and 2-3.

Science Indicators—1985

and development play a central role in all of these economic thrusts. As figure 2-4 reveals, R&D expenditure growth compares favorably with recent changes in selected economic activities.

In summary, national investment in research and development has been increasing in constant dollars since the mid-1970's. This expansion began during a period of slowed economic growth, and may be expected to continue during the current period of sustained economic recovery.

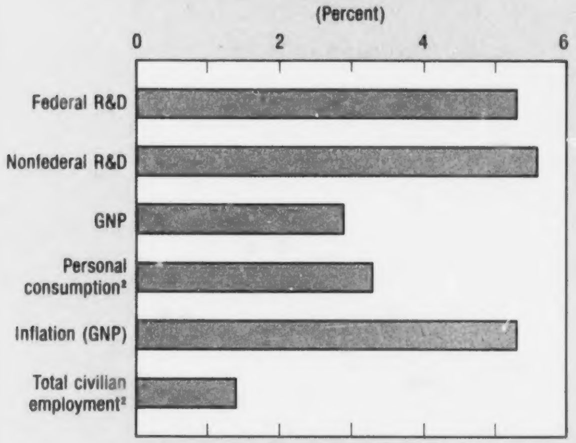
Sources of Support for Research and Development

The industrial sector emerged as the primary source of R&D support in the United States in 1980, accounting for 50 percent of total R&D funding that year. (See appendix table 2-3.) By 1985, industrial R&D spending had climbed to $22.9 billion (in constant dollars). Federal expenditures represent the next largest source of R&D support, accounting for an estimated 47 percent of the R&D total in 1985. Between 1984 and 1985, it is estimated that both Federal and industrial R&D expenditures will have grown by 7 percent. (See table 2-1.)

R&D spending strategies differ by sector. Levels of R&D investment in the industrial sector represent the sum total of R&D spending decisions by a diversity of U.S. firms—each with its own economic history and reasons for funding research and development. Firms view investing in research and development as a means of strengthening the S/T base underlying economic growth and greater technological competitiveness in international markets. Growth in industrial R&D spending might thus be expected to be greater for firms characterized by rapid technological change, based on the present economic climate and national R&D priorities.

Figure 2-4

Average annual rate of change in national R&D expenditures and selected measures of U.S. economic activity: 1980-1985[1]



[1] Expenditures deflated using GNP implicit price deflators to convert current dollars to constant 1972 dollars.

[2] 1980 through 1984 only.

SOURCES: Council of Economic Advisors, *Economic Report of the President, 1985*, tables B-2 and B-30; and National Science Foundation, *National Patterns of Science and Technology Resources, 1985* (NSF 85-325).

Science Indicators—1985

Indeed, as figure 2-5 shows, the bulk of recent growth in industrial R&D is related to expansion of R&D funding by "high technology" firms.[10] Furthermore, as output has slowed in more mature industries and heavy losses of employment have occurred, R&D investment by those industries has also declined.[11]

Federal funding for research and development in recent years has been designed to strengthen support for defense and for nondefense basic research.[12] Reductions in R&D programs not considered appropriate for Federal support by the current Administration are responsible in part for the more moderate growth observed in Federal R&D expenditures, as shown in figure 2-5. Except where the Government itself is the intended user of a technology, the Administration views the private sector as better able to initiate technology than the Government.[13]

Table 2-1. Average annual rate of change in national R&D expenditures, by source of support, in constant dollars.

Source	1976-80	1980-84	1984-85
	(Percent)		
Industry	6.6	5.5	6.8
Federal Government	2.3	4.7	7.4
Universities/colleges	4.9	5.5	6.7
Nonprofit institutions	2.9	0.8	6.0

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

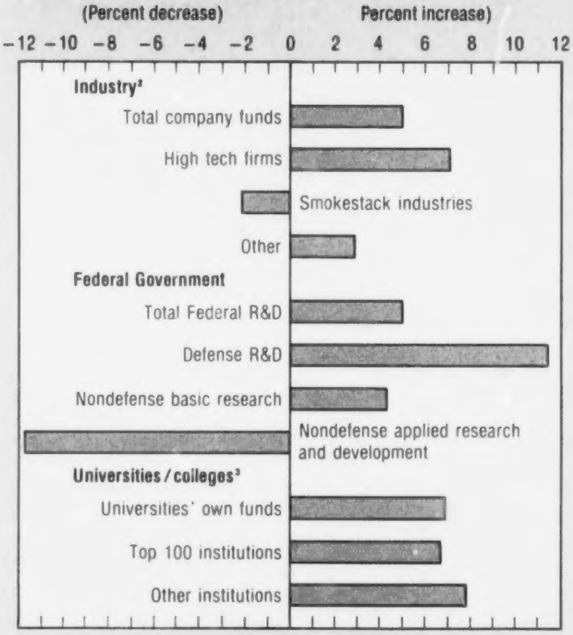
See appendix table 2-3.

Science Indicators—1985

Although the academic sector and nonprofit institutions together provide little more than 3 percent of total national support for research and development, they serve as special resources in the science community. In the academic

Figure 2-5

Average annual rates of change in national R&D spending[1] for selected components of the economic sector: 1980-84



[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

[2] Based on 1980 to 1983 changes only. See appendix table 2-4.

[3] Based on 1980 to 1983 changes only.

SOURCES: U.S. Department of Commerce, *1984 U.S. Industrial Outlook* (1984); National Science Foundation, *National Patterns of Science and Technology Resources, 1985* (NSF 85-325); and National Science Foundation, *Academic Science and Engineering, R&D Funds FY 1983* (NSF 85-308), and earlier years.

Science Indicators—1985

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[10] "High technology" firms are characterized by a high proportion of engineers and scientists to total employment, and rapid technological change. "Smokestack" industries represent older technologies and slower rates of technological change. See, for example, Creamans, et al. (1984), Dewar (1982); and Abernathy, Clark, and Kantrow (1983).

[11] The smokestack sector lost about 565,000 jobs from 1979 to 1983 and is projected to regain only 227,000 by 1987. In contrast, employment in the high technology sector grew by 217,000 jobs from 1979 to 1983. See Creamans, et al. (1984). New approaches to the support of research relevant to the rebuilding of some of these industries are now being developed. For example, an effort has been made in recent months to establish a research partnership between the steel industry and Federal research laboratories. See Keyworth (1984d).

[12] For the latest statement of Federal R&D budget priorities, see Executive Office of the President (1985), pp. K-1 through K-7.

[13] See, for example, Nelson and Langlois (1983); and Keyworth (1984c).

sector, R&D expenditures from the universities' own funds[14] have grown steadily from just over one-fifth of total academic R&D funding in 1960 to one-quarter in 1985.[15] University support of research and development has expanded at a slightly higher rate in institutions outside the top 100 institutions.[16] (See figure 2-5.) However, the top 100 R&D institutions account for over 80 percent of all R&D expenditures provided by U.S. universities. Thus, R&D funding growth in the top 100 institutions has accounted for as much as three-fourths of the growth in universities' own R&D funds in recent years.

Performers of Research and Development

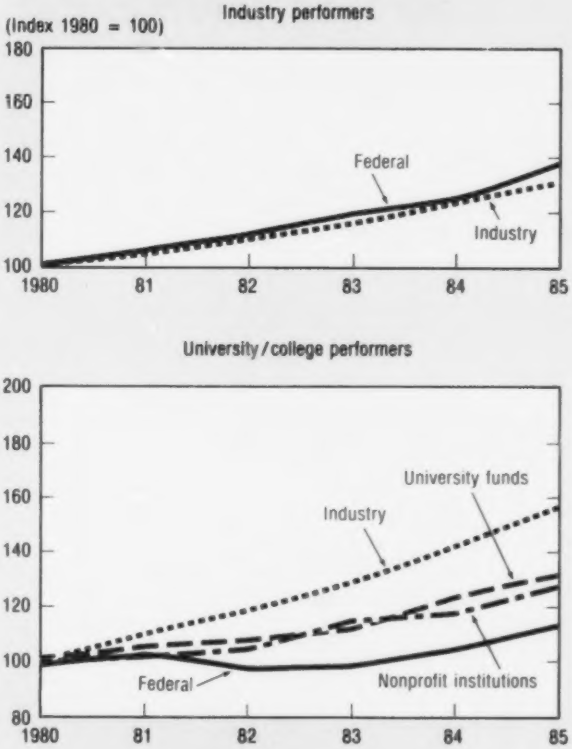
The industrial sector performs the majority of research and development in the United States, consuming an estimated 73 percent of all R&D expenditures in 1985. In the early 1960's, the industrial sector performed as much as 78 percent of all research and development in the U.S. This share declined to a level of approximately 69 percent in 1969, a level which persisted throughout the decade which followed. In the last few years the proportion of research and development performed by the industrial sector has grown to 73 percent of the total, approaching once again the historically high levels evident two-and-a-half decades ago. (See appendix table 2-5.)

Between 1980 and 1985, industrial R&D expenditures from all sources grew nearly 34 percent in constant dollars, attributable primarily to expanded Federal investment. Federal funding for research and development performed in the industrial sector grew by 38 percent in constant dollars during that period (primarily through defense R&D contracting), while that representing company funding increased by 32 percent.[17] (See figure 2-6.) Industrial performance of research and development is estimated to have grown 6 percent between 1983 and 1984 (once an adjustment for inflation has been made) and is expected to grow another 8 percent (in constant dollars) between 1984 and 1985.

The Federal Government accounts for the next largest share of national R&D performance, as measured in R&D expenditures. (See appendix table 2-5.) In 1985, this sector accounted for 12 percent of all R&D performed that year. Fluctuations evident in the relative share of national research and development performed by this sector are related to shifts in Federal R&D priorities. In the early 1970's, Federal performance of research and development accounted for as much as 16 percent of total R&D conducted in the United States. The relatively greater prominence of the Government role was related at that time to a combination of special emphases on space, environmental, and energy R&D.[18] Since 1980, the share of national R&D performed by these laboratories has remained essentially level.

Constant-dollar expenditures for the remaining R&D-performing sectors are estimated to have grown at an average annual rate of 2.8 percent between 1980 and 1985. The growth of R&D performance in these sectors had slowed to a rate of 3.0 percent between 1970 and 1980, after increasing at an average annual rate of 8.9 percent in the 1960's. R&D performance in the academic sector accounts for most of the growth observed in the non-Governmental, nonindustrial sectors, having expanded at an estimated average annual rate of 3.8 percent in constant-dollars between 1980 and 1985. (See appendix table 2-5.) Between 1980 and 1985, funding for university-affiliated Federally funded

Figure 2-6
Relative change in the source of R&D support by selected performer in constant 1972 dollars[1]



[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1985* (NSF 85-325).

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[14] That is, funds from sources other than the Federal Government, or the private sector, but including support provided by State and local Governments.

[15] See NSF (1984c), p. 28.

[16] As ranked by total R&D expenditures in 1983.

[17] Studies of the effects of Government support of industrial R&D suggest that in the aggregate, Federal funds stimulate private R&D spending. Estimates vary widely, however, with respect to the amount of change in private sector R&D investment associated with changes in Government R&D spending. See, for example, Mansfield (1982), and Levy and Terleckyj (1983).

[18] See, for example, NSF (1984c), pp. 8-11.

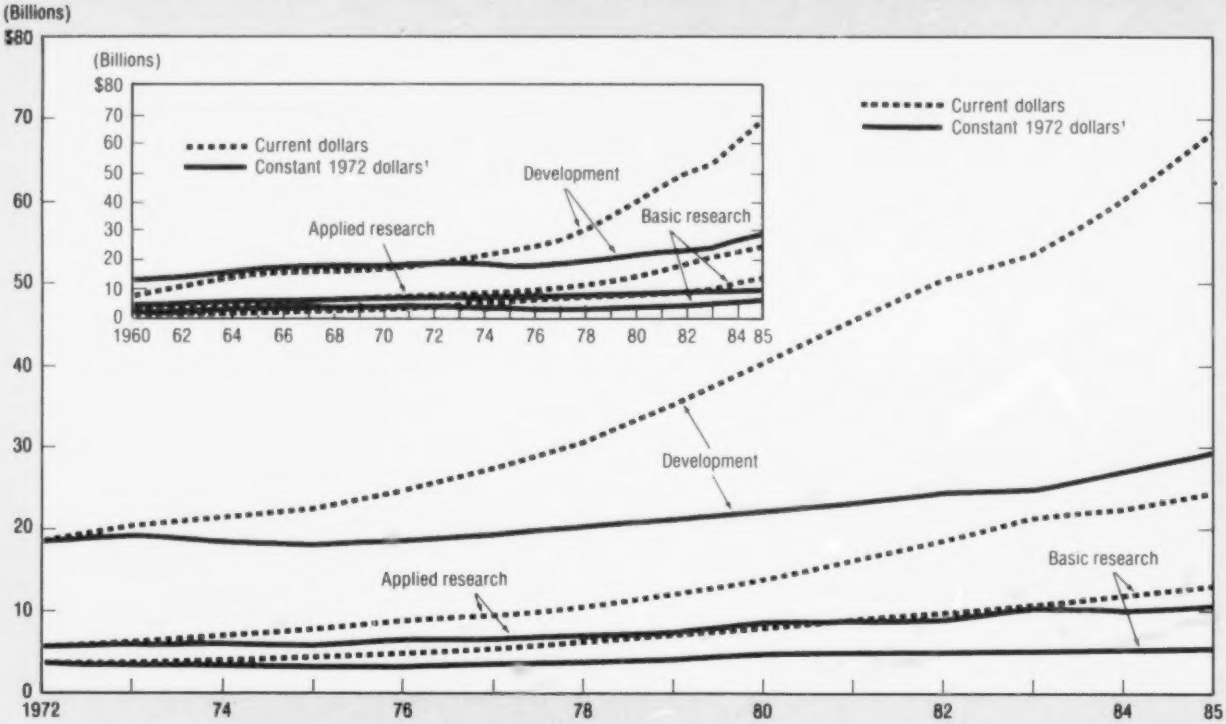
R&D centers (FFRDC's)[19] and for R&D performers in the nonprofit sector remained essentially level in constant-dollar terms.

In summary, the industrial sector continues to dominate the performance of U.S. research and development. Modest increments have occurred, however, in the constant-dollar expenditures evident in the other performing sectors, especially between 1984 and 1985.

Character of Research and Development

Trends in national support for research and development may be analyzed by the character of the funded activity: basic research, applied research, or development. Basic research has as its objective a fuller knowledge or understanding of the subject under study, rather than a practical application. Applied research, on the other hand, is directed toward gaining knowledge or understanding necessary for determining the means by which a recognized or specific need may be met.[20] Development is the systematic use of the knowledge or understanding gained from research, directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processes. Between 1976 and 1985, national expenditures for basic research and for applied research increased at an average annual rate of 4.6 percent and 4.9 percent, respectively (in constant-dollars), while spending for development grew at an average yearly rate of 5.1 percent. (See figure 2-7.) Between 1980 and 1985, national support for applied research and development continued its high rate of growth, expanding at average annual rates of 6.0 and 5.5 percent, respectively, in constant-dollar terms. By comparison, the aver-

Figure 2-7
National R&D expenditures by character of work



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Estimates are shown for 1983, 1984, and 1985.
See appendix table 2-6.

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[19] FFRDC's are organizations exclusively or substantially financed by the Federal Government to meet a particular requirement or to provide major facilities for research and training purposes. Data are presented here for those FFRDC's administered by universities. Information regarding those FFRDC's administered by industrial firms or nonprofit institutions is included in the totals for the relevant performing sectors and is not broken out separately.

[20] For the technical definitions of research and development utilized by NSF, see appendix table 2-6.

age annual growth rate for basic research over the 1980-85 period in constant dollars was 4.5 percent. Between 1984 and 1985, basic research grew at a higher rate than applied research (6.0 versus 4.5 percent), but slightly less than development (8.0 percent).

Significant gains have been made in national support for basic research in the past two-and-a-half decades. Less than 9 percent of total national R&D support was directed to basic research in 1960; by 1985, the share stood at just over 12 percent, a level which has remained essentially constant since 1976. (See table 2-2.)

The Federal Government continues to be the primary source of basic research support in the United States, funding two-thirds of the total national investment in basic research in 1985. (See appendix table 2-7.) The Federal share has declined slightly since 1980, however, owing to the comparatively greater growth of industrial support for basic research during that period. Between 1980 and 1985, industrial support for basic research grew at an average annual constant-dollar rate of 8.5 percent in contrast to the average yearly rate of 3.7 percent for Federal support. Despite the more rapid growth in industrial funding of basic research, the proportion of industry's R&D investment devoted to basic research remains small compared to that of the Federal Government. Basic research funding represented an estimated 5 percent of total industrial R&D support in 1985, compared to 18 percent of total Federal R&D support.

Although the proportion of national funding devoted to applied research has remained constant at about one-fifth of the total over the past 25 years, substantial changes have taken place in the sources of applied research support. In 1960, Federal funding for applied research represented 58 percent of total national expenditures in that area; by 1985, the Federal share had dropped to 37 percent.

Industrial investment in applied research exceeded that of the Federal Government for the first time in 1980 and has continued to grow. Between 1980 and 1985, industrial support of applied research grew at an average annual rate of 10.2 percent in constant dollars so that, by 1985, industrial funding represented 58 percent of total national support for applied research.

Federal support for applied research has declined in recent years as efforts have been made to de-emphasize near-term research programs not considered appropriate for Federal investment.[21] Between 1980 and 1985, Federal support for applied research peaked at a level of $4.4 billion (in constant dollars) in 1983 and declined by about 12 percent by 1985. (See appendix table 2-8.)

Approximately 66 percent of total national R&D expenditures supported development activities in 1985, a proportion which has remained essentially constant over the last two-and-a-half decades. Between 1980 and 1985, national support for development grew at an average annual rate of 5.4 percent in constant dollars. Federal funding for development grew at an average annual rate of 7.1 percent during that time, primarily fueled by growth in defense R&D expenditures, while industrial support of development grew more slowly at an average yearly rate of 4.1 percent. Nevertheless, industry funded 53 percent of the Nation's total development activities in 1985. (See appendix table 2-9.)

Table 2-2. National R&D expenditures, by character of work, as a percent of total R&D expenditures.

	1960	1976	1980	1985
	(Percent)			
Total	100.0	100.0	100.0	100.0
Basic research	8.9	12.8	12.9	12.5
Applied research	22.3	23.2	22.4	21.5
Development	68.8	64.1	64.6	66.0

See appendix tables 2-6 and 2-3.

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TRENDS IN FEDERAL SUPPORT FOR RESEARCH AND DEVELOPMENT

Federal support for research and development is provided primarily to meet national needs appropriate for Government action, such as research for national defense. The primary function served by national defense R&D is to maintain superior science and technology, both as a source of future procurements and as a protection against adverse technological surprise. In addition, the technology must be applied effectively, which requires phasing it into use rapidly and efficiently. National defense R&D programs thus support long-range research for technological progress and research directed toward the improvement of military capabilities.

Funding is also provided by the Federal Government to meet broad national needs where the Government shares responsibility with the private sector. Included in this category are R&D activities that improve the quality of life or support the Nation's long-term economic strength and are of such a nature that private firms or consortia cannot alone realize a sufficient return to warrant individual investment.

A desire to sustain U.S. leadership in technological development has also led the Federal Government to try to create an environment in which innovation may be more likely to flourish. Evidence of this desire is found in the tax incentives intended to stimulate greater private R&D investment and the acquisition of new equipment and facilities. This section describes the nature of recent changes in the Federal R&D budget within the context of these scientific and economic goals and the factors that have influenced those trends.

Federal Outlays for Research and Development

Federal outlays for research and development and R&D plant will reach an estimated $50.8 billion in 1985. (See appendix table 2-10.) This total represents just over 5 percent of the total outlays in the 1985 budget.[22] (See figure 2-8.) As a share of total Federal outlays, Federal support for research and development and R&D plant peaked at 13 percent in 1965, declining steadily thereafter to a low of 5 percent in 1981. The significant expansion of Federal outlays for benefit payments to individuals, farm price support programs, and similar open-ended and fixed-cost programs relative to the expansion of Federal support for R&D led to the decline in this ratio.[23] Since 1981, slight gains have been made in this ratio as R&D funding growth outpaced the growth of Federal outlays as a whole.

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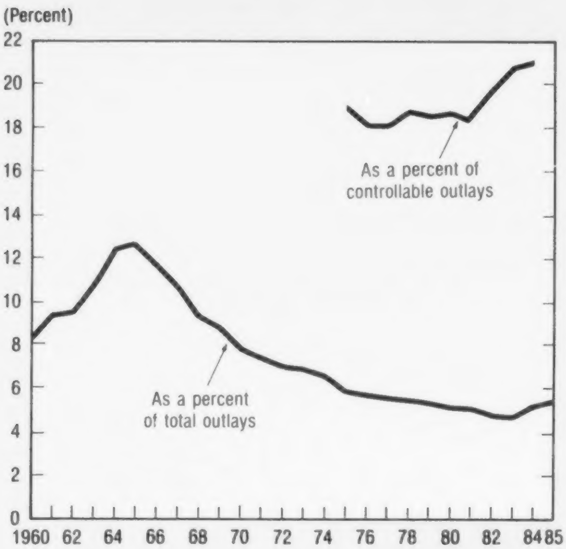
[21] See Executive Office of the President (1985), p. K-1.

Federal R&D outlays[24] are treated as controllable parts of the budget. As a share of controllable outlays, Federal outlays for research and development and R&D plant have grown from a level of 19 percent in 1975 to an estimated 21 percent in 1984. (See figure 2-8.)

Figure 2-8

Federal outlays for R&D and R&D plant as a percent of Federal budget outlays



See appendix table 2-10.

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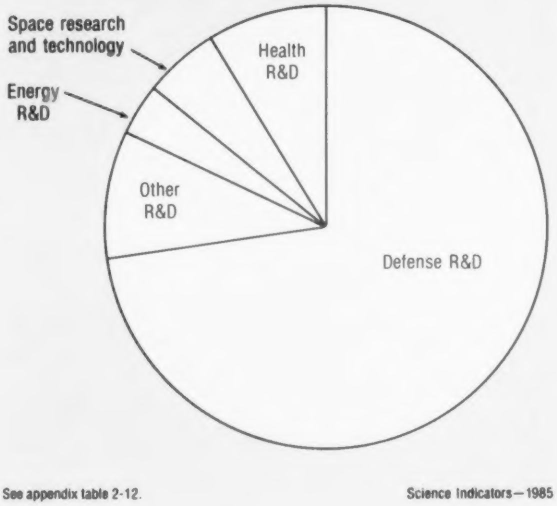
Functional Areas of Federal R&D Funding

The Office of Management and Budget (OMB) divides the Federal budget into functional categories that reflect areas of Federal responsibility. Of the 16 categories that contain R&D programs, national defense receives the largest share of Federal investment in research and development.[25] Health R&D accounts for the next largest R&D budget category, followed by space research and technology and energy R&D. (See figure 2-9.)

The overall pattern of Federal R&D spending is one of growth, although the emphasis of that growth is in basic research and in development. Development accounts for an estimated 77 percent of the expansion of the Federal R&D budget authority between 1980 and 1985, largely as a result of increased defense spending. In the nondefense area, basic research is estimated to have grown 21 percent between 1980 and 1985 in constant-dollar terms.[26] Support for applied research and development in nondefense areas is estimated to have declined by 17 percent and 55 percent, respectively, in constant-dollar terms between 1980 and 1985. The overall effect was a 26-percent growth in

Figure 2-9

Relative distribution of Federal funds for research and development by budget functions: 1986



See appendix table 2-12.

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[22] Government agencies commit Federal funds for research and development only when they have been authorized to do so by law. Once authorized, funds are committed by the agencies to intramural projects, or to extramural contractors or grantees. In the case of intramural payments, obligation and outlay data are very close. In the case of extramural payments, lags occur. These data differ from "expenditure" data presented elsewhere in this chapter, which are derived from information reported by R&D performers.

[23] Between 1975 and 1985, payments for individuals through such programs as social security or public assistance are estimated to be rising at an average annual rate of 10.9 percent. Federal support for research and development and R&D plant have grown at an estimated average annual rate of 9.6 percent during the same period. See Executive Office of the President (1984), pp. 9-44.

[24] Including outlays for R&D plant.

[25] Two of the 17 budget functions have no R&D component. For purposes of analyzing R&D support patterns, the budget function "general science, space, and technology" has been divided into two separate categories: "space research and technology" and "general science," thus yielding 16 categories for analysis.

[26] See NSF (1984d).

real terms in Federal support for basic research between 1980 and 1985, a 7-percent decline in applied research, and a 44-percent increase in support for development.

National defense. Research and development programs for national defense lay the groundwork for weapons systems and support equipment. The R&D portion of the total defense budget authority is estimated to be 13 percent, up from a level of 9 percent in 1980.[27] Emphasis on strategic modernization[28] through research and development has resulted in a proposed 18 percent increment (in constant-dollars) in defense R&D between 1985 and 1986. (See appendix table 2-12.) This increase would represent the continuation of an acceleration in defense R&D funding which began in 1980. (See figure 2-10.) Between 1980 and 1985, Federal funds for defense R&D grew at an estimated average annual rate of 11.7 percent in constant-dollar terms, following a 20-year period of essentially no real growth for research and development in this area.[29] As a percent of total Federal R&D obligations, support for defense R&D has not yet returned to the share reported in 1960. However, defense R&D is expected to rise from a recent low of 49 percent in 1979 to 73 percent in 1986, thus bringing it up to levels generally observed in the early 1960's.

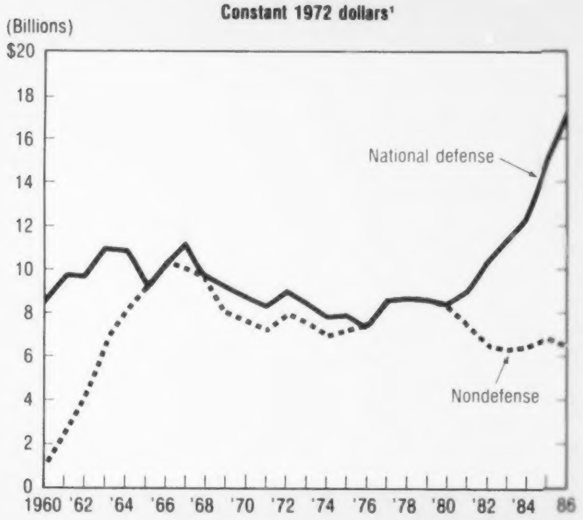
Other Federal R&D. Federal support for research and development in areas other than defense has emphasized strong growth in basic research. Federal obligations for nondefense R&D will have declined in constant-dollar terms at an average annual rate of 1.8 percent between 1976 and 1986; this decline is largely due to sustained reductions in Federal support for development even as support for basic research has grown. Between 1976 and 1986, Federal support for development in nondefense areas was estimated to have declined at an average annual rate of 8.8 percent in constant dollars.[30] As a result, basic research shifted from being the smallest portion of nondefense R&D in 1976 (24 percent) to the largest share in 1986 (an estimated 43 percent). (See figure 2-11.) Increased emphasis on basic research and de-emphasis of development are reflected in total nondefense R&D represented by the various budget functions:

Percent share of nondefense R&D

	1980	*1986*
Health	22	32
Space	28	20
Energy	22	14
General science[31]	7	13
All other	21	21

Figure 2-10

Federal R&D budget authority for national defense



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

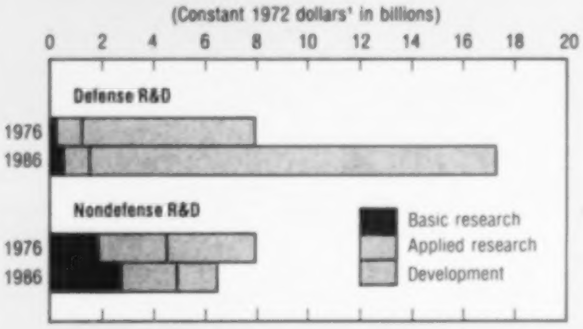
NOTE: Estimates are shown for 1985 and 1986.

See appendix table 2-11.

Science Indicators—1985

Figure 2-11

Relative changes in Federal obligations for defense and nondefense R&D by character of work in constant 1972 dollars¹



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *Federal R&D Funding: The 1975-85 Decade* (March, 1984) and unpublished tabulations.

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[27] See NSF (1985c).

[28] See Weinberger (1984); DeLauer (1984); General Accounting Office (1983b); Keyworth (1984e and g); and Zraket (1984).

[29] Between 1960 and 1980, defense R&D actually declined at an average annual rate of 0.4 percent in constant-dollar terms.

[30] The emphasis of Federal R&D investment is on longer-term research and development. For programs related to nearer-term R&D goals, including demonstration projects, it is believed that the private sector has greater expertise than the Federal Government in bringing new technologies to the marketplace.

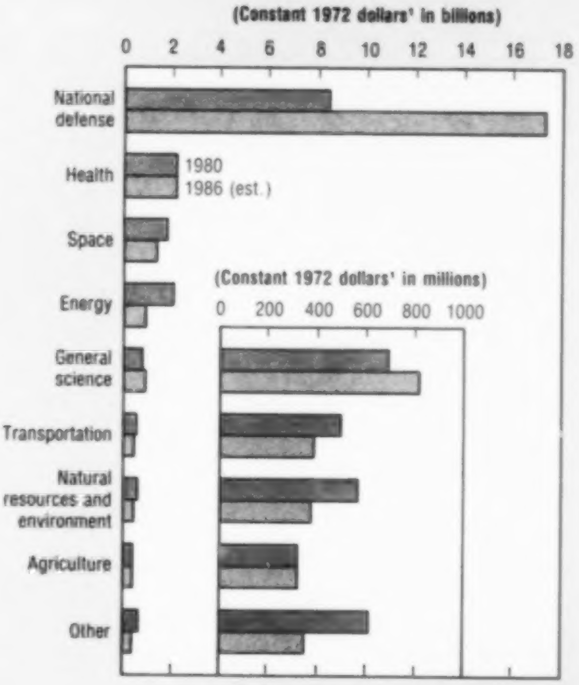
[31] This function consists of the National Science Foundation and two programs of the Department of Energy (high energy physics and nuclear physics). The programs that fall within this function are viewed as contributing to the Nation's scientific base in an even broader sense than the basic research supported by mission agencies. Ninety-six percent of the R&D total in this budget function consists of basic research. See NSF (1985).

Health funding has increased its share of overall nondefense R&D funding since 1980, although in constant-dollar terms R&D funding in this budget function has remained essentially level at $2.0 billion from 1980 to 1986. (See figure 2-12.)

Space research and technology declined as a share of nondefense R&D between 1980 and 1986. This decline is linked to an absolute decrease in Federal funding for space research and technology, which dropped from a total of $1.7 billion (in constant dollars) in 1980 to a low of $1.0 billion in 1983 before rising to an estimated constant dollar level of $1.3 billion in 1986. Decreases and subsequent growth in these figures are related to the initiation, development, and completion of space transportation systems research programs, such as those behind the deployment of the space shuttle or the spacelab.[32]

Figure 2-12

Federal obligations for research and development in constant 1972 dollars[1]



[1]GNP implicit deflators used to convert current dollars to constant 1972 dollars.

See appendix table 2-12. Science Indicators—1985

Federal R&D Strategies for Technological Competitiveness

A central theme of current economic policy is the improvement of industrial performance and national economic welfare. To achieve these goals, the Federal Government has introduced, or has proposed, a number of measures designed to stimulate the rate and direction of technological innovation. Among these measures are mechanisms for increasing private sector investment in research and development, including tax incentives to stimulate greater private sector investment in research and development and the acquisition of new facilities and equipment, regulatory policies that are favorable to innovation in industry, and fiscal and monetary policies which assure a stable economy within which firms may operate.[33]

Another way in which the Federal Government has attempted to stimulate long-range technological change is through the direct support of basic research. Federal investment in basic research, especially in the physical sciences and engineering, has been linked to the emergence of new discoveries, new technologies, and new industries that enhance U.S. competitiveness.[34] This section analyzes the impact of greater support for basic research on the relative distribution of Federal funding across the various fields of science and engineering and on the choice of performer. Special consideration is given to the enhanced role of the university sector in the performance of basic research relevant to increased technological competitiveness.

New roles for science and engineering. In 1985, Federal obligations for basic research were estimated to have reached $7.6 billion, a 6-percent increment in constant-dollar terms from their 1984 level, and a 24 percent increment from their 1980 level. Five agencies provided almost 90 percent of total Federal support for basic research in 1985 (See figure 2-13.)

Federal policies emphasizing basic research have resulted in significant expansion in Federal support for the computer sciences, mathematics, and engineering. Between 1980 and 1985, Federal support for basic research in the computer sciences increased at an average annual rate of 21.0 percent (see figure 2-14), bringing the total amount of support to an estimated $124.6 million in 1985. Federal support for basic research in mathematics and engineering increased at an average annual rate of 19.0 percent and 13.2 percent, respectively, during the same period. Despite this growth, however, Federal support for basic research in mathematics and the computer sciences remained at less than 4 percent of total Federal support for basic research in 1985, while the proportion of Federal support for basic research in engineering grew 1 percentage point, from 10 percent of the total in 1980 to 11 percent in 1985. Gains in funding support, although at more modest levels, also occurred in the remaining fields of science. (See appendix table 2-14.)

Much of the growth reported in mathematics and computer sciences is related to increased support for basic

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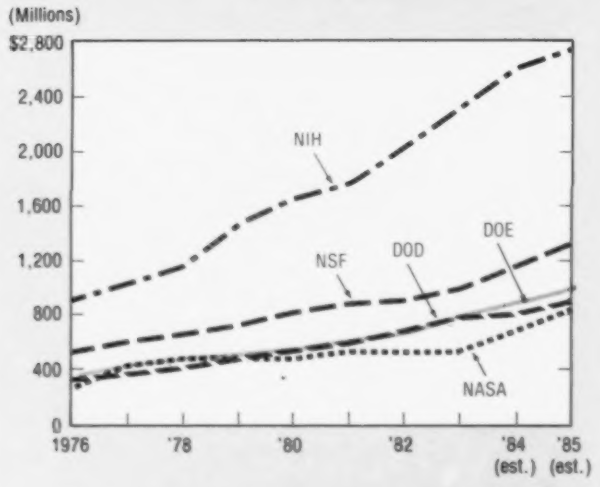
[32] For example, when the space shuttle program shifted to its operational phase, R&D funding programs declined significantly. See NSB (1983), Congressional Budget Office (1984a); and NSF (1985). A 29 percent increase in funding in 1986 over 1985 levels for space transportation systems will emphasize spacelab and space station activities. See NSF (1985).

[33] Technology advances and their adoption by industry have been found to influence economic growth. See Roessner (1980), p. 429, Nelson (1982); and Rothwell and Zegveld (1982.)

[34] See President's Commission on Industrial Competitiveness (1985).

Figure 2-13
Federal obligations for basic research by agency



See appendix table 2-13.   Science Indicators—1985

research as a whole by DOD.[35] Between 1980 and 1985, DOD support for basic research in general grew at an average annual rate of 5.1 percent in constant-dollar terms, compared with the 4.3 percent growth observed for the remaining Federal agencies. Differences are also evident in the relative growth in DOD support for basic research across the various fields of science and engineering between 1980 and 1985, as shown below.

Average annual change, 1980-1985

	DOD	*Nondefense agencies*
Computer Sciences	23.0%	21.0%
Mathematics	23.0	16.1
Engineering	10.5	14.7
Other	9.0	9.7

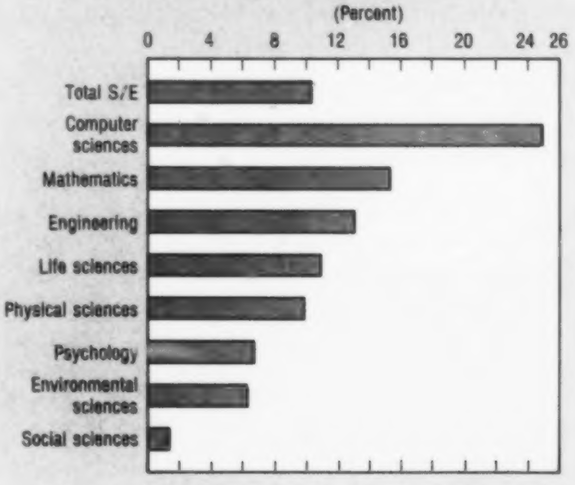
By 1985, DOD funding accounted for an estimated 46 percent of total Federal basic research support in mathematics, 46 percent in computer science, and 32 percent in engineering. (See figure 2-15.)

Although Federal agencies have increased their support for basic research, little change has occurred in their choice of research performers. (See appendix table 2-15.) Just as they did in 1976, NIH and NSF directed the vast majority of their basic research support in 1985 to the university sector. Similarly, NASA has continued to use its own intramural laboratories for the conduct of basic research, while DOE has relied on the university-affiliated FFRDC's.[36] Little change has occurred between 1976 and 1985 in these agency-specific performer patterns, with the exception of the Department of Defense. In 1976, DOD intramural research laboratories performed approximately 50 percent of the basic research supported by the agency. (See appendix table 2-15). By 1985, that share was estimated to have declined to 34 percent. Meanwhile, support grew for university-based basic research: in 1985, university performance of basic research accounted for 50 percent of total DOD basic research support, up from 34 percent in 1976.

As figure 2-16 illustrates, between 1980 and 1985 DOD support for basic research in the university sector grew at an average annual rate of 10.5 percent (in constant dollars). Significant growth in university research funded by NSF and DOE followed. While NIH support grew more slowly during that period (4.9 percent on average each year in constant dollars), support provided by that agency still represented the primary source of Federal support for basic research in the university sector in 1984.

Federal initiatives in the academic sector. In addition to receiving increased support for basic research, the academic sector is expected to play a greater role in the technology transfer process. The Federal Government has undertaken a number of initiatives to remove barriers to the establishment of workable university-industry research relationships. The promotion of private-sector R&D investments through tax credits and appropriate modifications

Figure 2-14
Average annual change in Federal obligations for basic research by field of science: 1980-85



See appendix table 2-14.   Science Indicators—1985

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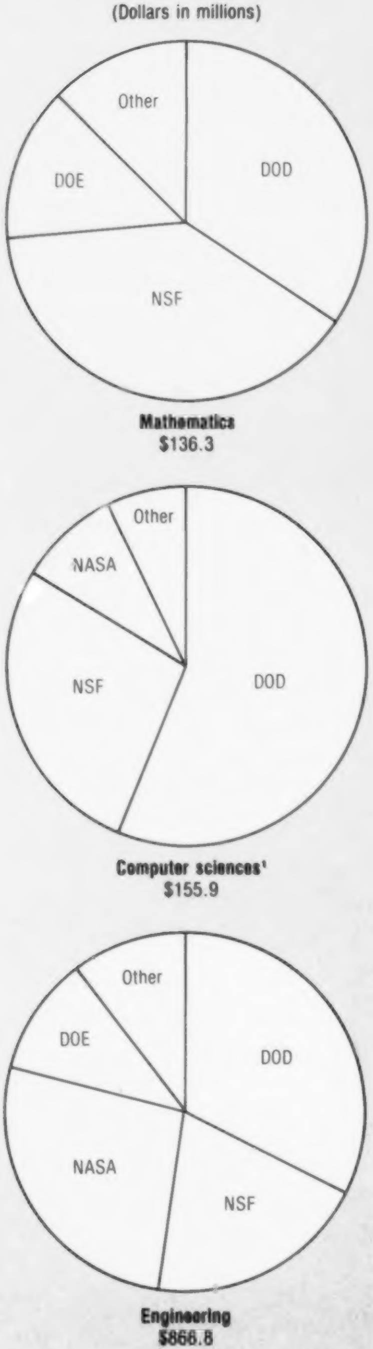
[35] Increased DOD support for basic research in mathematics, the computer sciences, and in certain microelectronic fields is related primarily to the potential application of new machine intelligence technology to defense programs. See, for example, Weinberger (1984), p. 263, and National Academy of Sciences (1983a).

[36] DOE support for basic research performed by those FFRDC's represented nearly two-thirds of total DOE support for basic research in 1985.

Figure 2-15

Relative share of Federal support for basic research in mathematics, computer sciences, and engineering by agency:1985



[1] Includes computer sciences and mathematics NEC.

SOURCE: National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1983, 1984, and 1985* vol. XXXIII (NSF 84-336).

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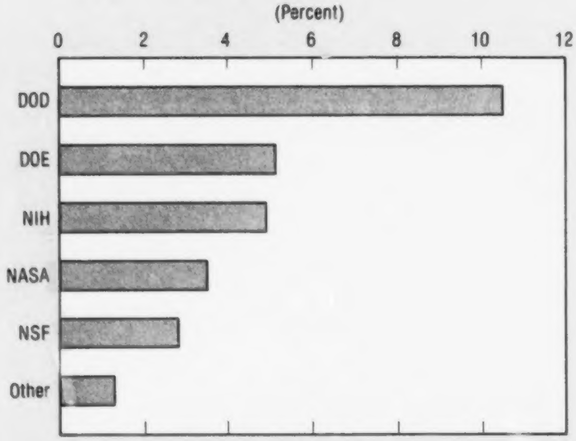
Figure 2-16

Average annual change in Federal obligations for basic research performed in universities and colleges¹ in constant 1972 dollars² by source of agency support: 1980-85



[1] Excluding university-affiliated Federally funded research and development centers.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *Federal Funds for Research and Development: Detailed Historical Tables, Fiscal Years 1967-1985*, 1985.

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of antitrust laws has encouraged industrial research relationships with universities. Furthermore, changes in Government patent policies to encourage performers of basic research to bring their ideas further along the innovation process toward commercialization have had similar consequences.[37]

Federal funding of cooperative research centers is another mechanism which has received considerable attention in recent years as a means to stimulate technological advance and, thus, competitiveness in international markets. Since 1973 the National Science Foundation has supported a program of Cooperative Research Centers in which several companies join with one or more universities to devise and support a program of mutually interesting research. Between 1978 and 1984 NSF support for these Centers—there were 20 operational Centers in 1984—grew at an average annual rate of 20 percent, while industrial support increased at more than twice that rate.[38]

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[37] The Economic Recovery Tax Act of 1981 (PL 97-34) includes incremental R&D tax credits for the support of R&D and for the contribution of research equipment to universities. In 1983, the President directed Federal agencies to extend the policy of contractor ownership of inventions to all R&D contractors, thereby assuring that Government-funded technology is available to the private sector for commercial use. See U.S. Department of Commerce (1984), pp. 9-17. The Federal role in funding industrial extension has been limited. See General Accounting Office (1983a, pp. 35-53.)

[38] The NSF program requires the centers to become self-sustaining within 5 years, that is, to achieve 100 percent non-Government funding. As of October 1, 1984, 20 centers were in place, the first of which (MIT) had been established in 1973.

This successful NSF model was incorporated into the Stevenson-Wydler Technology Innovation Act of 1980, which authorized the Department of Commerce and the NSF to create Centers for Industrial Technology affiliated with universities or other nonprofit institutions.[39] However, with the change in administrations in 1981, the new policy held that the Federal government should not determine the research programs of the Centers. Since NSF's Cooperative Centers left this determination up to the academic and industrial partners (subject, of course, to peer review), the NSF Cooperative Centers Program was continued and expanded; however, no Centers for Industrial Technology were supported by NSF or by the Department of Commerce.

The Cooperative Centers Program, itself, has continued, and the concept has been expanded in NSF's new Engineering Research Centers Program, initiated in 1985. These centers have strong commitments from industry and emphasize engineering education as well as research focused on solving problems important to engineering practitioners.

University-Industry Cooperative Research

Centers are also forming without the assistance of the Federal Government. Although the exact number of such centers is not known, recent surveys of State efforts in this area suggest that university-based cooperative research centers are becoming established with greater frequency than they have in the past. This increase is due primarily to the States' awareness of the economic benefits to be gained by attracting industries to their regions through university-based research arrangements.[40]

Independent Research and Development

In addition to providing direct support for industrial research and development, the Federal Government has supported R&D activities of industrial contractors for a number of years through a program of Independent Research and Development (IR&D). IR&D consists of in-house research and development carried out by private contractors on technology projects they have choosen to better prepare their firms to respond to the Government's national security needs. For projects which appear to have direct security relevance, the Federal Government allows contractors to recover a certain level of their IR&D costs as overhead charges allocated to Federal contracts on the same basis as general and administrative costs.[41]

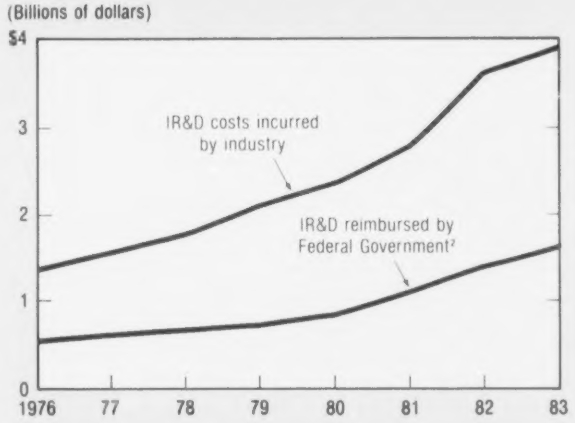
In 1983, industrial contractors were estimated to have incurred $3.9 billion in IR&D costs. (See figure 2-17.) Of this amount, the Federal Government accepted $2.9 billion in overhead negotiations, or about 75 percent of the total.[42] Of the amount reimbursed, over 90 percent or about $1.6 billion, represented DOD repayment in 1983. NASA provided another $76 million for IR&D that year.

The DOD and NASA have underwritten considerable industrial R&D activity through the IR&D program. IR&D reimbursements by these two agencies expanded from a level of $585 million in 1976 to an estimated total of $1.7 billion in 1983, growing at an average annual rate of 16.0 percent. (See appendix table 2-16.) However, when compared with total R&D support provided by these agencies, the IR&D contributions remain a relatively modest share (6 percent). (See appendix table 2-17.)

By supporting IR&D, the Government seeks to create a climate which encourages the development of innovative concepts for defense and space systems and maintains the technical competence of the many contractors who can respond competitively to Government-generated requests for proposals.[43]

In fiscal year 1985, the Department of Defense plans to mount a new initiative with respect to IR&D policy. To foster greater university-industry interaction, the DOD will raise IR&D ceilings for individual firms which are able to demonstrate increased university interaction using

Figure 2-17
Costs incurred for IR&D[1] and Federal reimbursement



[1] Independent research and development.
[2] Chiefly DOD and NASA.
See appendix table 2-16.

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[39] See U.S. Department of Commerce (1984), pp. 1-3.

[40] See National Governors' Association (1983). See also Office of Technology Assessment (1984b); Branscomb (1984b); and Task Force on High Technology Initiatives (1984).

[41] Each major contractor is required to negotiate in advance an agreement on the size of its IR&D program, following a technical evaluation by the Department of Defense. A company which spends beyond its negotiated IR&D ceiling may not allocate the extra costs to DOD contracts. Each year the Defense Contract Audit Agency submits a report of IR&D costs for approximately 100 major defense contractors to Congress. See Office of the Secretary of Defense (1984). Bid and proposal (B&P) activities of contractors, while generally not regarded as R&D, are closely related to IR&D, although not reported here. From the company's standpoint they are a general overhead expense, like IR&D, necessary to stay in business. B&P costs are administered in the same way as IR&D except that there is no technical evaluation of company B&P plans.

[42] However, not all that is accepted is reimbursed in any given year. Almost half of the IR&D costs—just over $500 million—accepted by the Government in 1983 were not reimbursed.

[43] See U.S. Department of Defense Instruction 5100.66.

their IR&D funds.[44] The program can thus serve as a vehicle for strengthening university-industry interactions by encouraging more IR&D work to be contracted out to universities. Such a plan is seen as a management tool to strengthen research within IR&D, to foster closer cooperation between academia and industry, and "to speed the transitioning of technology out of basic [university] research."[45]

Research Support for Food and Agriculture

As U.S. agriculture has moved from a resource-based industry to an S/T-based industry, and from a domestically-oriented market to an international one, concern has grown about the ability of the U.S. agricultural research system to keep pace with the need for productivity-enhancing research. Concern has tended to focus on the failure of the agricultural sciences to be at the forefront of the recent biotechnology revolution and on the need for a better integration of research resources to create a more modern, national agricultural research enterprise.[46]

U.S. agriculture has changed considerably in the past few decades. For example, between 1910 and 1980, farm production tripled while agricultural employment declined by 80 percent.[47] This dramatic increase in agricultural productivity has been linked to the increased mechanization of farming and the utilization of agricultural research advances such as hybrid seeds, improved livestock feed, herbicides, and pesticides.[48] In 1983, agricultural exports represented about 18 percent of total U.S. exports. Agricultural exports totaled 25 percent of U.S. farm sales revenues and the output of about 35 percent of the harvested cropland. In that same year, the United States exported three-fifths of its wheat; two-fifths of its rice, soybeans, and cotton; and one-third of its tobacco.

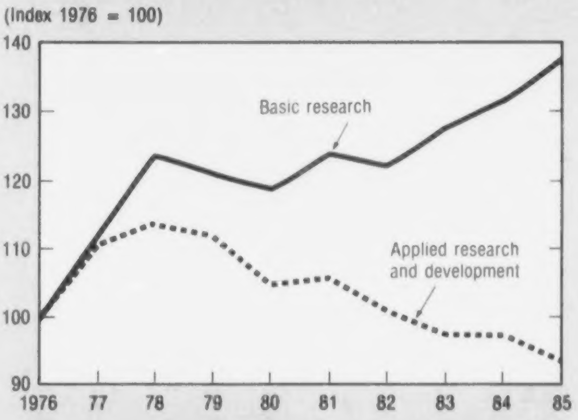
Federal support represents about one-third of total national R&D support for agriculture. (See appendix table 2-18.) Federal support is provided chiefly by the U.S. Department of Agriculture (USDA) through the Agricultural Research Service (ARS), which operates a network of over 140 research facilities, and through the Cooperative State Research Service (CSRS), which contributes to the operation of the 52 State Agricultural Experiment Stations (SAES) affiliated for the most part with land-grant universities.

Federal agricultural research policy today recognizes that the surplus of U.S. agricultural products evident in the 1980's could be a transient phenomenon. Small variations in climatic conditions, for example, could turn present excesses into major world food shortages.[49] Furthermore, there is increasing concern about the productivity levels of our natural resource base—concerns that derive from the possible environmental consequences of placing increased pressure on agricultural and forestry production.[50] As a result, Federal support for agricultural research has increasingly addressed long-term agricultural interests. As figure 2-18 illustrates, USDA support for basic research grew by about 36 percent between 1980 and 1985 in constant-dollar terms, while support for applied research and development declined by about 9 percent.

The impact of this trend toward greater basic research support in USDA can be detected in the shift in the distribution of funding among ARS, CSRS, and other parts of USDA. Between 1980 and 1985, support for basic research through the intramural programs of the ARS grew at an average annual rate of 8.7 percent, while funding for basic research conducted primarily at U.S. land grant universities through CSRS programs grew by 11.3 percent per year. (See appendix table 2-19.) Increased support for basic research through the programs of the Cooperative State Research Service is expected to stimulate the development of a knowledge base in biotechnology.[51] Although rapid developments have occurred in biotechnology related to

Figure 2-18

Relative change in USDA obligations for basic research and for applied research and development in agriculture in constant 1972 dollars[1]



[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *Federal Funds for Research and Development: Detailed Historical Tables, Fiscal Years 1967-1985*, 1985.

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[44] See "DOD Guidelines for Contractor Presentation of IR&D Information," September, 1984.

[45] See DeLauer (1982).

[46] See, for example, General Accounting Office (1983c); Ruttan (1983); National Academy of Sciences (1983b); Evenson (1983); Keyworth (1984a); Joint Council on Food and Agricultural Sciences (1984); and Lipman-Blumen (1984).

[47] An accompanying trend has been a steady decrease in the total number of farms. Between 1978 and 1982, the total number of farms declined from 2,257,775 to 2,241,124. Most of the loss occurred in farms between 50 and 1999 acres. The number of large farms has grown steadily since 1925, while little change has occurred in the total amount of cultivated farmland. See U.S. Bureau of the Census (1984); Busch, et al. (1984b); and Council of Economic Advisors (1984).

[48] See, for example, Office of Technology Assessment (1981); Executive Office of the President (1982); Battelle Memorial Institute (1983); Farrell (1984); and Thompson (1984).

[49] See Farrell (1984); and Schweikhardt and Bonnen (1985).

[50] See, for example, Bentley (1984); Clarke (1984); Farrell (1984); and the Joint Council on Food and Agricultural Sciences (1984).

[51] Both the Joint Council on Food and Agricultural Sciences (1984) and the State Agricultural Experiment Stations' Committee on Organization and Policy (see Clarke, 1984), as well as the National Academy of Sciences (1983b), have identified biotechnology as the number one research priority in the next few years.

lower organisms, many barriers remain in the application of biotechnology to higher plants and animals. Federal emphasis on basic research, especially through the CSRS, is expected to produce usable biotechnology to improve the efficiency and productivity of agriculture.[52]

Most of the initial work in biotechnology has occurred outside the mainstream of agricultural research in the sense that the research activities have been undertaken predominantly in academic natural science departments. Funding has been provided largely by the National Institutes of Health, or, in the case of plant biology, by the National Science Foundation.[53]

Recognizing the potential for biotechnology to improve agricultural productivity, a number of Federal agencies other than the USDA have increased their support for work directly in the agricultural sciences in recent years. As appendix table 2-19 reveals, non-USDA Federal support for basic research in the agricultural sciences increased at an average annual rate of 32.0 percent between 1980 and 1985, although still accounting for less than 2 percent of the Government's basic research funding in this area.

The State Agricultural Experiment Stations and the Agricultural Research Service are viewed as having a unique opportunity to help achieve full utilization of the new biotechnology research capabilities within agriculture. Through extension work, new knowledge and technology are likely to be placed in the hands of users as quickly as possible.[54] A recent survey of the 52 SAES and the ARS revealed that by the end of 1982, 42 SAES had some biotechnology research underway, although the average project had only 2 full-time equivalent (FTE) researchers assigned to it. (See appendix table 2-20.) As table 2-3 indicates, the majority of funding for biotechnology projects at the SAES was provided by the Federal Government in 1982. The ARS reported a total of 94 biotechnology projects underway in 1982, at a level of funding of $13.8 million.

Table 2-3. National expenditures for biotechnology at State Agricultural Experiment Stations, by source of support: 1982

	Expenditures (in thousands)	Percent of total
Total	$41.6	100.0
State	16.2	39.0
Federal	19.8	47.7
Private	5.5	13.2

SOURCE: National Association of State Universities and Land-Grant Colleges (1983).

Science Indicators—1985

OVERVIEW

National support for research and development continues to grow in the United States, with total national R&D expenditures having reached $107 billion in 1985, the highest level ever. Favorable economic conditions have enabled industry and other private sources to increase their R&D spending, while new funding policies have contributed to the growth of Federal R&D support—especially in the areas of defense R&D and nondefense basic research. By 1985, national R&D expenditures represented 2.7 percent of the GNP, up from a recent low of 2.2 percent in 1978.

The industrial sector surpassed the Federal Government in 1980 as the primary source of R&D support in the United States. Since that time, industrial R&D funding has also expanded at a higher rate than Federal R&D funding. By 1985, industrial R&D spending reached $53.2 billion, or 50 percent of total national R&D support, while Federal R&D spending totaled $49.8 billion, or 47 percent of the total. Much of the growth in industrial R&D funding is related to increased R&D spending by high-technology industries, with declines evident in the R&D funding by other industries. Industrial funding continues to emphasize primarily development activities (which account for 69 percent of total industrial R&D expenditures), with applied research and basic research accounting for 27 percent and 5 percent of industrial R&D support, respectively.

As the other major source of R&D support in the United States, Federal R&D policies are of substantial interest to the S/T communities. In recent years, the Federal Government has significantly expanded research and development for national defense purposes. Between 1980 and 1985, Federal funds for defense R&D grew at an average annual rate of 11.7 percent in constant-dollar terms, while those for nondefense R&D remained essentially stable in constant dollar terms. However, in the nondefense area, Federal basic research programs have experienced strong growth. Between 1980 and 1986, Federal support for nondefense basic research shifted from 28 percent of total Federal nondefense R&D to 43 percent, having grown at an average annual constant-dollar rate of 3.3 percent during that period.

With respect to performance, real growth has occurred in the industrial sector and in Federal Government performance of research and development. R&D expenditures for those two performers increased in constant dollars by 32 percent and 38 percent, respectively, between 1980 and 1985. Academic R&D also grew between 1980 and 1985 at a rate of 3.8 percent per year in constant dollars. This growth included a rapid increase in academic R&D expenditures between 1983 and 1984 (up 7 percent), which is expected to continue into 1985.

Virtually no change occurred in the distribution of national R&D expenditures between research and development. Development, which accounts for nearly two-thirds of total U.S. R&D spending, grew by about 8 percent between 1984 and 1985 in constant-dollar terms. National support for research expanded by 5 percent during the same period, with growing industrial support accounting for much of the growth in national support for research—mostly in applied research.

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[52] Definitions of biotechnology vary. In its June 1984 deliberations, the National Science Board adopted the definition of biotechnology developed by the Office of Technology Assessment (1984): "Biotechnology, broadly defined, includes any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop micro-organisms for living use." See NSB (1984); and also Office of Technology Assessment (1981); Office of Science and Technology Policy (1983); and Busch, et al. (1984a).

[53] See National Academy of Sciences (1983b); and Office of Technology Asesement (1984).

[54] See National Association of State Universities and Land Grant Colleges (1983), pp. 20-34.

Renewed national interest has led to substantial growth in basic research in recent years; between 1984 and 1985, for example, national support for basic research grew by 6 percent. About two-thirds of that growth represented increased Federal support, primarily in the physical sciences and engineering. The academic sector continues to serve as the primary performer of Federally supported basic research, accounting for about 51 percent of total Federal support in 1985.

However, the rate of growth of applied research expenditures has slowed in recent years. Between 1980 and 1984, national expenditures for applied research grew at an average annual rate of 6.4 percent in constant dollars, but grew by only 4.5 percent between 1984 and 1985. Federal support for applied research actually declined by 12 percent from the peak year of support in 1983 to 1985, in constant-dollar terms. This decline is consistent with the termination of R&D program support in areas deemed more appropriate for private sector R&D support. Indeed, as Federal support for applied research declined between 1983 and 1985, non-Federal support grew at an average annual constant-dollar rate of 7.8 percent.

In addition to receiving increased support for basic research, the academic sector is expected to play a greater role in the technology transfer process. The Federal Government has undertaken a number of initiatives to remove barriers to the improvement of university-industry research relationships. These initiatives include the promotion of private-sector R&D investment in universities through tax credits and changes in U.S. patent policies and through Federal funding of cooperative research centers based on university campuses. State efforts (described in more detail in the chapter in this report on academic science and engineering) have augmented Federal progress in this area.

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Chapter 3
Science and Engineering Personnel

Science and Engineering Personnel

Highlights

- *Rapid growth in employment of scientists and engineers.* The United States economy is increasingly based on scientific and technical activities. Between 1976 and 1983, employment of scientists and engineers (S/E's) increased more than three times as rapidly as total U.S. employment, almost three times as rapidly as real gross national product, and two times faster than total professional employment. As a result, S/E's accounted for 3.4 percent of the U.S. work force in 1983, up from 2.6 percent in 1976. Over the 1980-83 period, employment growth for S/E's accelerated, while the increase in overall U.S. employment and other resource indicators slowed considerably. (See p. 53.)
- *Faster growth of scientists, compared to engineers, driven by computer specialists.* In 1983, over one-half of the human resources devoted to science and technology (S/T) were engineers. However, during the period of 1976 to 1983, growth in employment of scientists outpaced that of engineers by a ratio of 3 to 2. This faster growth among scientists is attributed to the extraordinary growth in the employment of computer specialists. If this field were excluded, overall growth rates for S/E's would be essentially the same. (See pp. 53-54.)
- *Most scientists and engineers work in science and engineering-related jobs.* During the 1976-83 period, almost all S/E's who wanted jobs were employed; however, not all were in jobs related to science and engineering. Of the almost 3.5 million employed in 1983, about 3 million (88 percent) held jobs in S/E-related activities. Most scientists and engineers who held non-S/E jobs did so for "voluntary" reasons such as promotion, better pay, or locational preference. Only about 10 percent of those in non-S/E jobs (1.2 percent of all employed S/E's) were in non-S/E positions because they believed an S/E job was not available. Among doctoral S/E's, a small but increasing share worked in jobs outside of their own or related fields (11 percent in 1983 compared to 6 percent in 1973). (See p. 54.)
- *Labor market for scientists and engineers varies.* Labor market indicators suggest shortages in a few fields for engineers and a varied pattern among scientists. In 1983, a shortage of computer specialists was evident, while supply was about equal to demand for physical, mathematical, environmental, and life scientists. For social scientists and psychologists, supplies exceeded demand. (See pp. 59-60.)
- *Employment of scientists and engineers shift toward industry.* Between 1976 and 1983, employment of S/E's shifted toward industry and away from educational institutions and the Federal Government. Industrial employment rose 60 percent over the 7-year period, while employment in academia and the Federal Government rose 45 percent and 40 percent, respectively. In the industrial sector, employment of scientists, paced by computer specialists, rose faster than that of engineers: 82 percent versus 51 percent. Nonetheless, in 1983, about 51 percent of the scientists were employed by industry compared to 80 percent of the engineers. (See pp. 55-56.)
- *Work activities of scientists and engineers shift toward R&D and production.* Between 1976 and 1983, the primary work activities of S/E's shifted away from management and teaching and toward R&D and production activities. In 1983, about 32 percent of all S/E's were engaged in some aspect of R&D and another 13 percent worked primarily in production and related activities. (See p. 55.)
- *Work activities vary between scientists and engineers.* Scientists were more likely to be engaged in research and a combination of activities related to reporting, computing, and statistical work, while engineers were more likely to report involvement in development and production-related work. (See pp. 57, 58, 65, 66.)
- *Not all scientists and engineers hold their highest degree in science and engineering.* Of the 1.5 million scientists employed in 1982, almost 90 percent held their highest degree in a science field. About 70 percent of the 2 million engineers held their highest degree in an engineering field while another 3 percent held their highest degree in a science field. Of the remaining 27 percent, almost one-half held their highest degree in other fields such as business administration or education. (See pp. 58, 59, 66.)
- *Employment of women and minorities increased rapidly but they continued to be underrepresented in science and engineering.* Although women experienced significant employment gains between 1976 and 1983, they continued to be underrepresented in science and engineering. There were almost 440,000 women S/E's employed in 1983, up over 120 percent since 1976. In 1983, women accounted for 13 percent of all S/E's—25 percent of all scientists and 3 percent of all engineers. In contrast, about 44 percent of all employed persons were women as were 48 percent of all professional workers. (See pp. 62, 63, 69, 70.)
- *Among minorities, blacks and Hispanics were underrepresented in science and engineering, while Asians (U.S. citizens and non-citizens) were not underrepresented.* In 1983, about 2.4 percent of all S/E's were black and 2.1 percent were Hispanic. Asians represented 4.2 percent of all S/E's. In comparison, blacks accounted for 9 percent of the U.S. work force, Hispanics represented 7

percent, and Asians accounted for less than 2 percent. In 1983, blacks were more likely to be employed in the sciences, especially the life and social sciences, while Hispanics and Asians were more likely to be employed in engineering. (See pp. 62, 63, 70.)

- *Between 1976 and 1983, employment of black S/E's increased more rapidly than employment of either whites or Asians.* Over the 7-year period, employment of blacks rose 117 percent while that of whites rose 49 percent. Employment of Asians increased 36 percent over the same period. (See pp. 62, 63, 70.)
- *Foreign born individuals represent about 17 percent of the employed S/E's in the United States.* However, most foreign-born individuals are naturalized U.S. citizens. Only about 3.5 percent of the S/E work force are not U.S. citizens. Engineers are more likely than scientists to be foreign born (18 percent versus 14 percent). (See p.56.)

Scientists and engineers[1] play vital roles in the technological performance of U.S. industry in such areas as product or process innovation, quality control, and productivity enhancement. In addition, they conduct basic research to advance the understanding of nature, perform research and development in a variety of areas such as health and national defense, train the Nation's future S/E's, and contribute to the scientific and technological literacy of the Nation.

This chapter opens with an overview of the employment patterns of scientists and engineers as a group, including analyses of work activities and sectors of employment. A detailed analysis is then provided of engineers, followed by a similar analysis of scientists. Separate discussions of scientists and engineers reflect an appreciation of the different roles they play in U.S. science and technology efforts.

Utilization of Scientists and Engineers

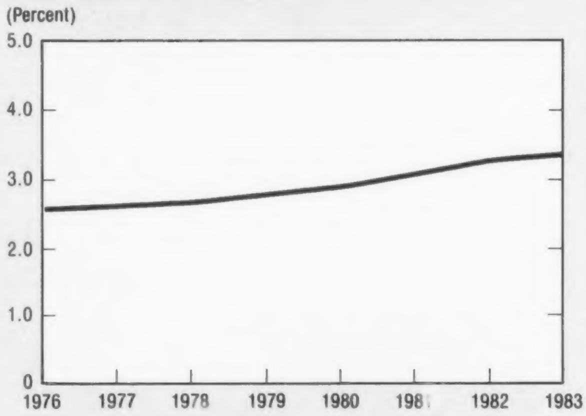
A principal indicator of the level of S/T activity in the U.S. is the number of employed S/E's. The human resource indicators presented below show that the U.S. economy is increasingly based on S&T activities.

During the 1976-83 period, employment of scientists and engineers increased more than three times as rapidly as total U.S. employment (49 percent versus 14 percent), almost three times as fast as overall economic activity as measured by real gross national product (18 percent), and two times faster than total professional employment (24 percent). As a result of the more rapid increase in S/E employment, the proportion of the U.S. work force employed as scientists or engineers increased from 2.6 percent in 1976 to 3.4 percent in 1983. (See figure 3-1.)

In recent years, changes have been more dramatic. Between 1980 and 1983, employment growth for scientists and engineers accelerated, while the increases in overall U.S. employment and other economic indicators slowed considerably. (See figure 3-2.) The more rapid increase in employment of S/E's results from two major factors: the relative concentration of S/E's in those industries (generally high-technology) where overall employment is increasing rapidly; and a change in the occupational mix of individual employers.

Growth in S/E employment varied between scientists and engineers and among fields. During the 1976-83 period[2], employment of scientists increased more rapidly than employment of engineers (6.9 percent per year versus 5.1 percent per year). Increases among scientists were affected by the above-average growth of computer specialists, who accounted for about two-fifths of the total employment increases among scientists. If computer specialists are excluded from the analysis, employment growth for scientists falls to 4.9 percent per year. Among engineers, the largest relative growth was recorded by electrical and chemical engineers. Engineering employment growth may have been inhibited by supply constraints; that is, it would have been greater if additional engineers had been available for employment. For example, about 18 percent of the engineers employed in 1983 held less than a bachelor's degree, suggesting employer upgrading of technicians.

Figure 3-1
Scientists and engineers as a percent of total U.S. workforce



See appendix table 3-1.

Science Indicators—1985

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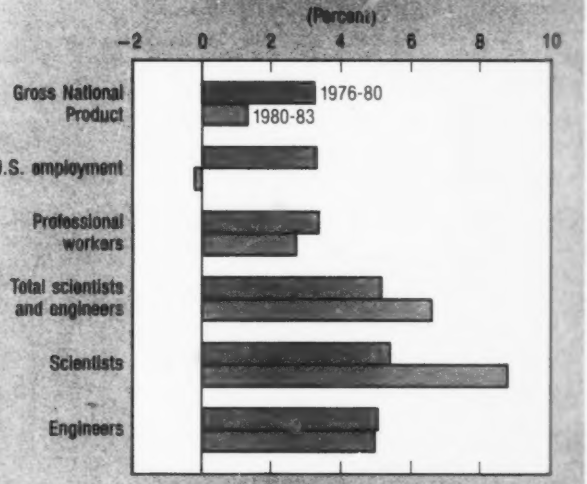
[1] Broadly speaking, a person is considered a scientist or engineer if he or she holds a degree in a S/E field (including social science), or is either employed in a S/E job, or professionally identifies himself or herself as a scientist or engineer (based on total education and work experience).

[2] 1976 is the earliest period in which comparable estimates by field are available.

Figure 3-2

Average annual growth in S/E employment and other manpower and economic variables



See appendix table 3-2.

Science Indicators—1985

The trends observed during the 1976-83 period were even more evident during the recent past. Between 1980 and 1983, employment of computer specialists rose at an annual rate of almost 19 percent, driving the increase in employment of scientists to a rate of 8.8 percent per year. The growth in the number of computer specialists, compared to the much smaller number of people earning degrees in this field, suggests substantial field mobility. Excluding computer specialists, employment of scientists increased by 6.4 percent per year, while employment of engineers grew at an annual rate of 5.0 percent over the 1980-83 period.

More than half of the human resources devoted to science and technology in 1983 were engineers. (See figure 3-3.) It is useful to distinguish between those who are or are not employed in science or engineering jobs. For a variety of reasons, some scientists and engineers hold jobs outside their own or related fields. Of the approximately 3.4 million employed scientists and engineers in 1983, 88 percent (about 3 million) reported they held jobs in science or engineering, with engineers (93 percent) more likely than scientists (82 percent) to hold such jobs. Between 1976 and 1983, employment in S/E jobs increased by 44 percent, much slower than the increase in employment in non-science and engineering (99 percent).

The fact that some scientists and engineers are employed in non-S/E jobs does not necessarily mean that they are being underutilized from a societal perspective. Their education and training may provide valuable insights to their non-technical activities, e.g., sales. Most S/E's who are working in non-S/E activity do so for "voluntary" reasons such as promotions, better pay, or location preference. In 1983, only about 10 percent of those in non-S/E positions believed an S/E job was not available.

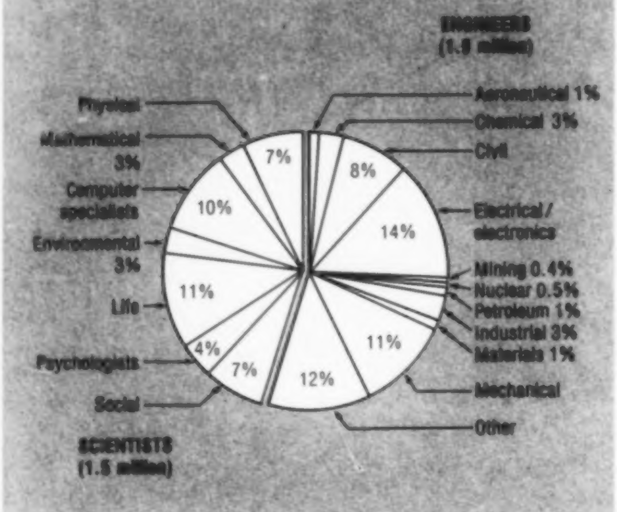
Employment of those holding S/E doctorates has also shown strong gains since 1973, reaching about 370,000 by 1983, an increase of 5.3 percent per year over the decade. (Employment of all scientists and engineers rose at a rate of 5.8 percent per year between 1976 and 1983.) Those employed in S/E activities increased by about 4.8 percent per year.

A smaller but increasing share of doctoral S/E's worked in jobs outside their own or related fields (11 percent in 1983, compared to 6 percent in 1973). Relatively few (8 percent) of those holding non-S/E positions indicated that they were so employed because they believed S/E jobs were not available. Since the mid-1970's, the number of employed S/E's holding doctorates has been increasing at a slower rate than the overall number of employed S/E's (4.4 percent per year for those holding doctorates and 5.3 percent per year for all S/E's).

In 1983, scientists at the doctoral level continued to outnumber engineers by about five to one. Between 1973 and 1983, growth rates varied considerably by field among doctoral S/E's (see figure 3-4), with below-average annual growth rates in the physical and mathematical sciences. The fastest growing employment field among doctoral S/E's was that of computer specialties. Between 1973 and 1983, employment in this field grew at an annual rate of about 16 percent, from 2,700 to about 12,000 in 1983. About 60 percent of the increased employment of computer specialists took place in industry, while about 30 percent took place in educational institutions. The growth in the employment of computer specialists reflects substantial field mobility at the doctoral level. About 80 percent of the employed computer specialists at the doctoral level earned their doc-

Figure 3-3

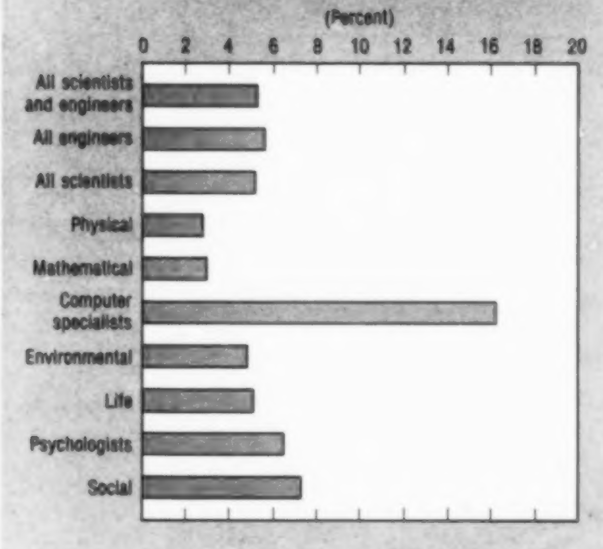
Employed scientists and engineers by field: 1983



See appendix table 3-3.

Science Indicators—1985

Figure 3-4
Annual growth rates of employed doctoral scientists and engineers by field: 1973-83



See appendix table 3-6. Science Indicators—1985

torates in a field other than computer science. This phenomenon may reflect a number of factors including the wide applicability of skills from many fields to computer science and the small supply, compared to demand, of those holding doctorates in computer science.[3]

Character of Science and Technology Activities

The work activities of scientists and engineers—as measured by the number, proportion, and distribution of those performing R&D, teaching, and other activities—are a direct indicator of the character of U.S. science and technology. (See figure 3-5.) These activities vary considerably by sector of the economy.

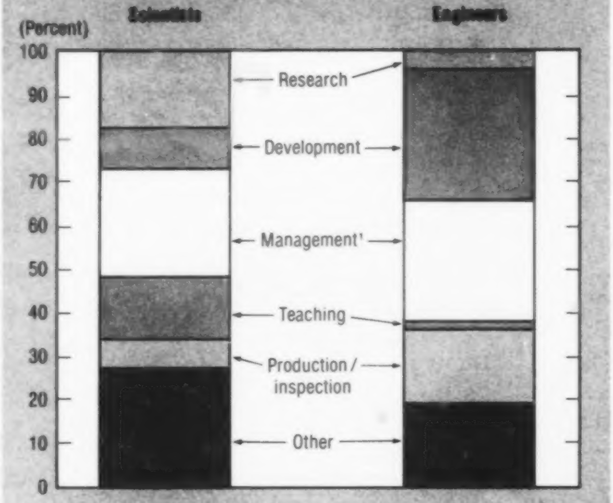
Between 1976 and 1983, the relative proportions of scientists and engineers primarily engaged in production, reporting and related activities, and development increased substantially. The proportions in research rose slightly, while the relative proportions primarily engaged in general management, R&D management, and teaching declined. The number of S/E's primarily engaged in research and development increased by 63 percent. By 1983, research and development was the primary activity of 31 percent of the Nation's S/E's. An additional 9 percent (about 288,000) were in R&D management. Thus, about two-fifths were involved in some aspect of R&D activity, with engineers more likely than scientists to report these activities (43 percent versus 34 percent). The situation was similar for S/E's holding doctorates. In 1983, 32 percent of the doctoral S/E's were working primarily in research and development, while an additional 8 percent cited R&D management as their primary activity.

About 7 percent of all scientists and engineers reported teaching as their primary work activity in 1983. Employment in teaching activities has grown at a somewhat slower rate than overall S/E employment during the 1976 to 1983 period (45 percent versus 49 percent). Scientists are much more likely than engineers to report teaching as their primary activity (13 percent versus 2 percent). This contrast is, in part, a result of differences in educational levels; a larger proportion of scientists than engineers hold doctorates (20 percent versus 3 percent), and are thus more likely to hold academic teaching positions. At the doctoral level, 29 percent of the S/E's reported teaching as their primary work activity in 1983, down from 36 percent in 1973. The decline in the proportion of doctorates reporting teaching as their primary activity is an example of the effect of intersectoral shifts on work activities.

During the 1976 to 1983 period, production and related activities, including quality control, were among the fastest-growing work areas of scientists, and especially engineers. The number primarily engaged in these activities rose almost 75 percent to about 443,000 in 1983—336,000 engineers and 107,000 scientists.

Most engineers and scientists (57 percent of 2.3 million) worked in business and industry in 1983, with engineers more likely than scientists to work in this sector (80 percent versus 50 percent). Educational institutions ranked a distant second as an employer of scientists and engineers (12 percent or almost 415,000). This sector employed 24

Figure 3-5
Primary work activities of scientists and engineers: 1983



¹Includes management of R&D.
See appendix table 3-9. Science Indicators—1985

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[3] For a more detailed discussion of occupational mobility, see NSF (1985).

percent of all scientists, but only 7 percent of all engineers in 1983. At the doctoral level, however, educational institutions were the major employer. In 1983, this sector employed 53 percent of doctoral-level scientists and engineers. Since the mid-1970's, the sectoral distribution of employed S/E's at all degree levels has changed only slightly, with small increases in the shares in business and industry and slight declines in the shares employed by educational institutions and by the Federal Government. Sectoral changes have been more pronounced at the doctoral level, with employment shifting from educational institutions to the industrial sector. In 1973, 59 percent of all doctoral S/E's were in educational institutions and 24 percent were in business and industry; in 1983, these respective proportions were 53 percent and 31 percent.

Foreign Born Scientists and Engineers

In 1982, almost 4 percent of employed U.S. S/E's were not U.S. citizens; while another 13 percent were naturalized U.S. citizens. Thus, almost 17 percent of the employed S/E's were foreign born. Engineers are more likely than scientists to be foreign born (18 percent versus 14 percent). Among engineers, the proportion who are foreign born ranges from 21 percent of the civil engineers to about 19 percent of the industrial and petroleum engineers. For scientists, the foreign born proportions range from 13 percent of the computer specialists to 19 percent of the chemists.

Foreign born S/E's differ from native born both in terms of type of employer and work activity. The foreign born are less likely to be employed by the U.S. military and government at all levels, and more likely to be employed by universities or colleges and non-profit organizations. Within industry, about 17 percent of the scientists and engineers were foreign born, roughly comparable to their proportions in the overall S/E work force.

With respect to work activities, the foreign born are less likely than the native born to be in management (16 percent versus 19 percent), and more likely to report research as their major activity (12 percent versus 10 percent). The foreign born are less likely than native born to report teaching as their major activity (8 percent versus 9 percent).

Approximately 25 percent of the foreign born scientists and engineers employed in the U.S. were Asians and 3 percent were black. The foreign born constitute a significant fraction of all Asian and black S/E's in the United States. Almost 80 percent of the Asians and 23 percent of the blacks were foreign born.

ENGINEERS

Employment Levels and Trends

Engineering is the second-largest profession in the United States, exceeded only by teaching. For men, engineering constitutes the largest professional area of employment. Engineering is also one of the fastest-growing professions in the United States. Between 1976 and 1980, for example, engineering employment grew much more rapidly than total professional employment (5.1 percent per year versus 3.4 percent per year).[4] Over the 1980-83 period, differences were more pronounced, with engineering employment increasing at a 5.0 percent annual rate, and professional employment increasing at a 2.7 percent annual rate.

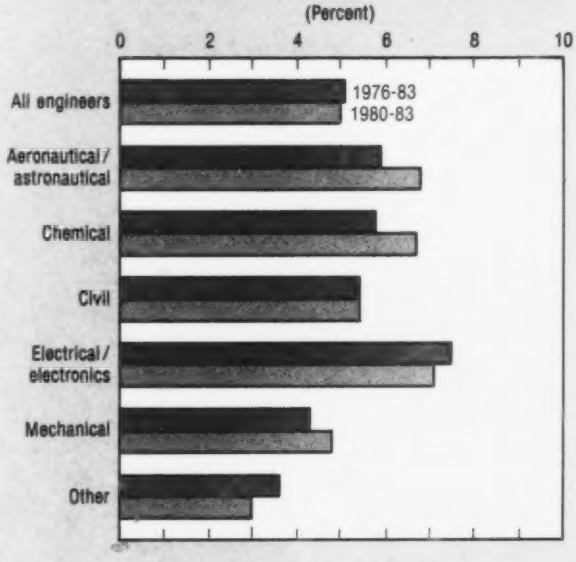
There were approximately 1.9 million employed engineers in the U.S. in 1983, over one-half million more than in 1976. Employment increases among engineers varied by field over the 1976 to 1983 period, with the greatest gains registered by electrical engineers. (See figure 3-6.)

Although there are at least 25 specialties recognized by the engineering profession, engineers are concentrated in relatively few fields. In 1983, about 470,000 (24 percent) were electrical or electronics engineers, and about 370,000 (19 percent) were mechanical engineers. At the other extreme, there were fewer than 20,000 nuclear engineers, and about 15,000 mining engineers.

Employment in Engineering Jobs. It is helpful for analytical purposes to distinguish between those who are engineers based on education and experience, and the employment of these individuals in engineering and related jobs. Of the 1.9 million employed engineers in 1983, about 93 percent (1.8 million) held engineering and related jobs. By field, this proportion varies in a fairly narrow range, from 88 percent of the mining engineers to over 95 percent of the aeronautical engineers. Since the mid-1970's, there has been virtually no change in the propensity of engineers to hold engineering and related jobs. Between 1976 and 1983, employment of all engineers and those in engineering jobs increased at similar rates (41 percent or 5.1 percent per year).

Engineers working outside their own or related field generally cite voluntary reasons for such employment, such

Figure 3-6
Annual growth rates of employed engineers by field



Based on appendix table 3-3 and unpublished data. Science Indicators—1985 as better pay, promotion, or locational preference. In 1983, only about 4 percent of those in non-engineering jobs (0.3 percent of all employed engineers) were so employed because they believed an engineering job was not available, with little variation by field. (See discussion on "Labor Market Indicators," below.)

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[4] See U.S. Department of Labor (1984), p. 14.

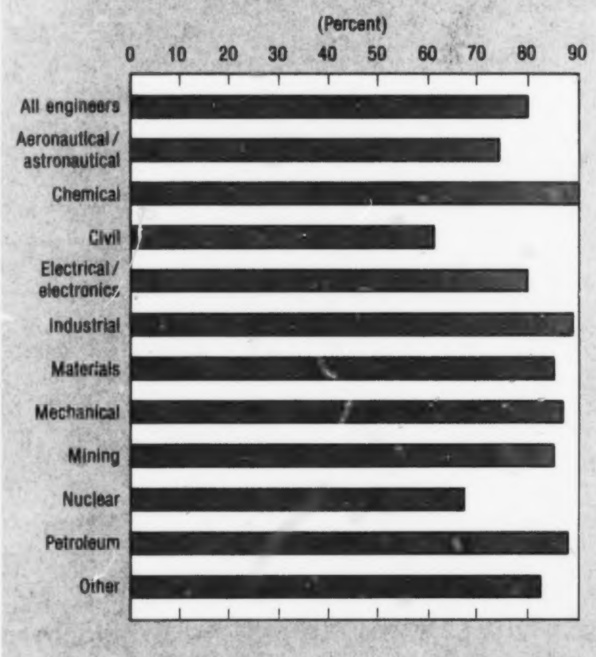
Sector of Employment

Most engineers—80 percent—worked in business and industry in 1983. (See figure 3-7.) The Federal Government ranked a distant second, employing about 7 percent of the Nation's engineers, while educational institutions employed about 3 percent. While the business and industry sector has historically been the largest employer of engineers, there has been a shift in recent years toward industry and away from other sectors.[5] Employment of engineers in industry increased by 50 percent between 1976 and 1983, a more rapid increase than that recorded for educational institutions (34 percent), the Federal Government (28 percent), or state and local governments (20 percent). As a result of these different growth rates, the share employed by the business and industry sector increased from 75 percent in 1976 to 80 percent in 1983, while the shares employed by other sectors showed modest declines.

Employment opportunities for engineers in the business and industry sector vary considerably by field. This sector employs almost 90 percent of all industrial engineers, but only 60 percent of all civil engineers. (See figure 3-8.) In addition to civil engineering, both aeronautical and nuclear engineering employment showed below-average representation in industry. Significant numbers of civil engineers are found in state and local governments, while substantial numbers of aeronautical and nuclear engineers are employed by the Federal Government.

Figure 3-8

Proportion of engineers employed in business and industry by field: 1983

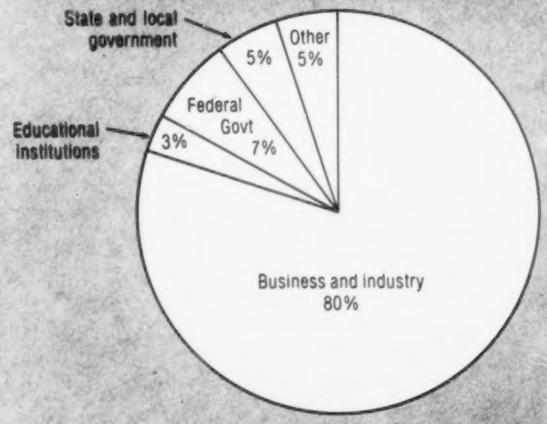


See appendix table 3-7.

Science Indicators—1985

Figure 3-7

Engineers by sector of employment: 1983



See appendix table 3-7.

Science Indicators—1985

Within the private sector, engineers are concentrated in relatively few industries. (See figure 3-9.) The electrical machinery, nonelectrical machinery, and transportation-equipment industries employ about 40 percent of the engineers in the private sector. The concentration of engineers in specific industries, however, varies by field. For example, almost 75 percent of the aeronautical engineers in industry are in the transportation equipment industry, primarily in firms manufacturing aircraft and related parts. By contrast, about 35 percent of the chemical engineers are in chemical manufacturing industries. Industrial and mechanical engineers are more uniformly distributed over the entire industrial spectrum. (See Chapter 4, "Industrial Science and Technology".)

Character of Engineering Activities

The work activities of engineers, as measured by the number and proportion of those performing research and development, teaching, and other activities, are indicators of the character of the U.S. technological effort. In addition, because innovations depend in part on research and development, the number and proportion involved in research and development may be leading indicators of the Nation's innovative efforts.

The work activities of engineers have shifted over time. (See figure 3-10.) Between 1976 and 1983, the proportions

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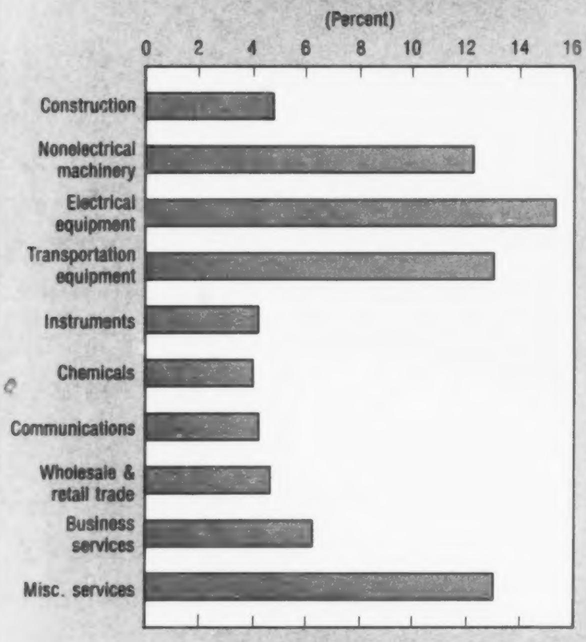
[5] For a more detailed discussion of engineers employed in industry, see Chapter 4, "Industrial Science and Technology."

Figure 3-9
Distribution of engineers in private industry by type of industry: 1982



SOURCE: National Science Foundation, unpublished data.

Science Indicators—1985

reporting research and development and production-related activities increased, while the proportions reporting management (both of research and development and other activities) declined. Relatively few engineers reported teaching as their major activity (fewer than 2 percent) in both 1976 and in 1983.

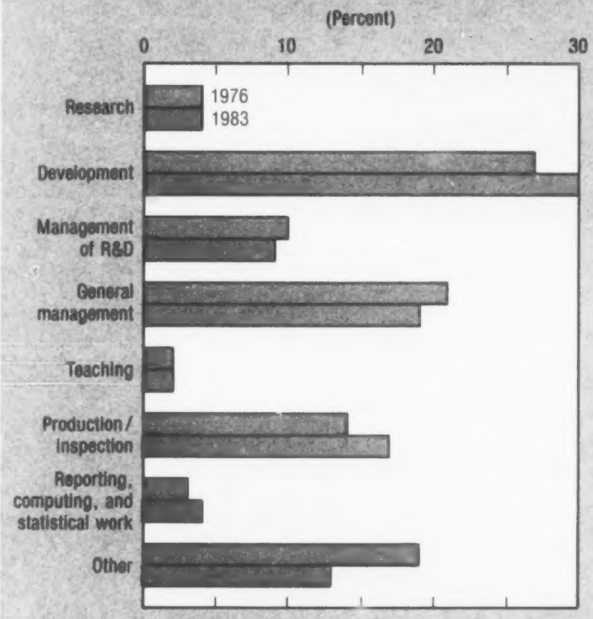
During the 1976-83 period, the number of engineers reporting research and development as their major activity increased by 57 percent to 665,000, or 34 percent of total engineering employment. Within research and development, the number in development (586,000) outweighed those in both basic and applied research (79,000) by about seven to one. Activities relating to production, including inspection and quality control, were among the fastest-growing activities for engineers. Between 1976 and 1983, employment of engineers in these activities rose by over 70 percent to 336,000. In 1983, about 17 percent of all engineers were engaged in production-related activities. Employment increases in these activities reflect the growing emphasis being placed on improved productivity, quality control, and international competitiveness in U.S. firms.

The work activities of engineers vary considerably by field. For example, the proportion of engineers reporting research and development as their primary activity ranged from 47 percent of all aeronautical engineers to about 19 percent of all civil engineers. (See figure 3-11.) Again, by way of example, aeronautical engineers are least likely to report they are engaged in production-related activities, while industrial and petroleum engineers are the most likely. The proportion of engineers reporting general management (non-R&D) as their major activity also varies by field. Civil and industrial engineers are the most likely to report management as their primary activity, while aeronautical engineers are the least likely. Work activity patterns may be more clearly understood when analyzed by sector of employment. This type of analysis may be found in Chapter 4, "Industrial Science and Technology" and Chapter 5, "Academic Scientists and Engineers."

Engineers by Field of Degree

Not all individuals classified as engineers hold their highest degree in engineering. Some hold less than a bachelor's degree while others hold their highest degree in areas such as business administration (e.g., an MBA degree). The relationship between a specific field of engineering and the field of highest degree provides an indicator of the extent of flexibility in the market for engineers. The degree of flexibility reflects both supply/demand conditions and occupational/field mobility. If there were little flexibility in the labor market, most chemical engineers, for example, would hold their highest degree in chemical engineering. If few chemical engineers held degrees in chemical engineering, the assumption would be that the market is very flexible and that demand greatly exceeds supply.

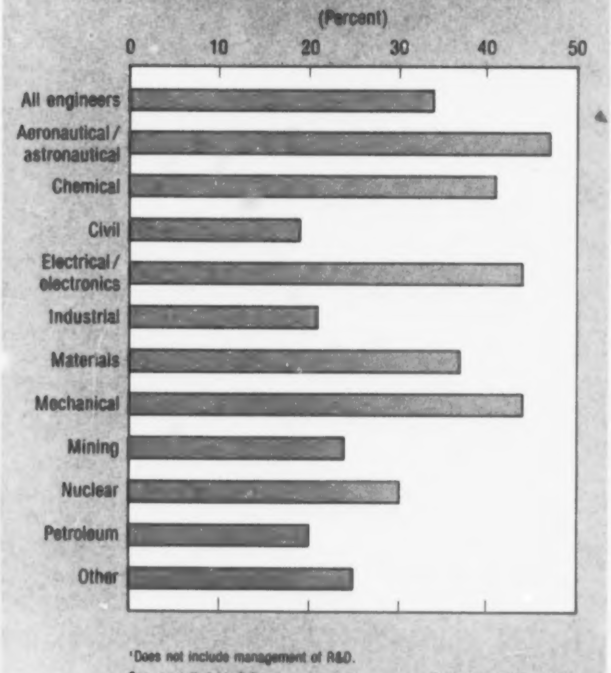
Figure 3-10
Primary work activities of employed engineers



See appendix table 3-9.

Science Indicators—1985

Figure 3-11
Proportion of employed engineers in research and development[1] by field: 1983



[1]Does not include management of R&D.
See appendix table 3-9.
Science Indicators—1985

In 1982, about 69 percent of the almost two million engineers reported their highest degree in one of the engineering fields, and about 3 percent reported a highest degree in one of the natural sciences (excluding social science and psychology), such as physics. Of the remainder (28 percent), almost half held less than a bachelor's degree, while the others held their highest degree in fields such as business administration or the social sciences.

The propensity for engineers to hold a degree in a field related to their field of engineering employment varied substantially across the engineering profession. For example, 82 percent of the chemical engineers reported their highest degree in chemical engineering. In contrast, only 23 percent of the nuclear engineers reported a degree in the same field; another 43 percent held a degree in another engineering discipline, and the remainder held degrees in other fields, primarily physics.

Labor Market Indicators

Labor market indicators are useful in assessing whether current supply is sufficient to meet the needs of the economy. In addition to standard labor market indicators, such as labor force participation and unemployment rates, the National Science Foundation has developed the S/E employment rate, the S/E underemployment rate, and the S/E underutilization rate as measures unique to engineers and scientists. No single statistic can provide a basis for measuring surpluses and shortages in particular fields, but some statistics, when examined together, allow inferences about market conditions. The statistics outlined below, as well as others examined in this section, reveal shortages in only a few fields of engineering.

Labor Force Participation. The engineering labor force includes those who are employed, either in or out of engineering and related jobs, and those who are not working but are seeking employment. The labor force is a measure of those who are economically active and thus directly available to carry out national efforts in science and technology. Labor force participation rates measure the fraction of the engineering population who are in the labor force.

Engineers continued to display a strong attachment to the labor force in 1983, with almost two million (95 percent) of the engineering population participating. This rate is higher than that for the general population completing four or more years of college (87 percent)[6] but the same as the rate for scientists. The difference in participation rates cannot be accounted for by differences in the composition, by sex, of these groups. When further stratified, male and female engineers had similar labor force participation rates (roughly 95 percent), and women engineers had higher rates than women in the total civilian labor force who completed four or more years of college (77 percent).[7]

There was little variation in labor force participation rates for engineers by field. Nuclear engineers had the highest rate (97 percent), while the lowest rate was recorded for chemical and mining engineers (93 percent). Most engineers (77 percent) not in the labor force were retired. Others were out of the labor force for a variety of reasons, such as poor health, full-time schooling, and family responsibilities.

Unemployment Rates. The unemployment rate is a standard measure of labor market conditions. It measures the proportion of those in the labor force who are not employed but are seeking employment. In 1983, the unemployment rate for engineers was 1.9 percent (down from 3.2 percent in 1976), substantially below the rate for the total U.S. labor force (9.6 percent), and somewhat lower than the rates for all professional workers (3.0 percent)[8] and all scientists (2.6 percent).

There was some variation in unemployment rates among fields of engineering. (See figure 3-12.) The highest unemployment rate was recorded for chemical engineers (2.9 percent); the lowest was for electrical/electronics engineers (1.2 percent).

S/E Employment Rates. The S/E employment rate measures the extent to which those engineers who are employed hold jobs in engineering-related work. Depending on the specific reasons for non-S/E employment, a low S/E employment rate could be an indicator of underutilization. Factors relating to non-S/E employment include lack of available S/E jobs, higher pay for non-S/E employment, location, or preference for a job outside of science or engineering.

In 1983, the S/E employment rate for engineers was 93 percent, with little variation by field. Mining engineers

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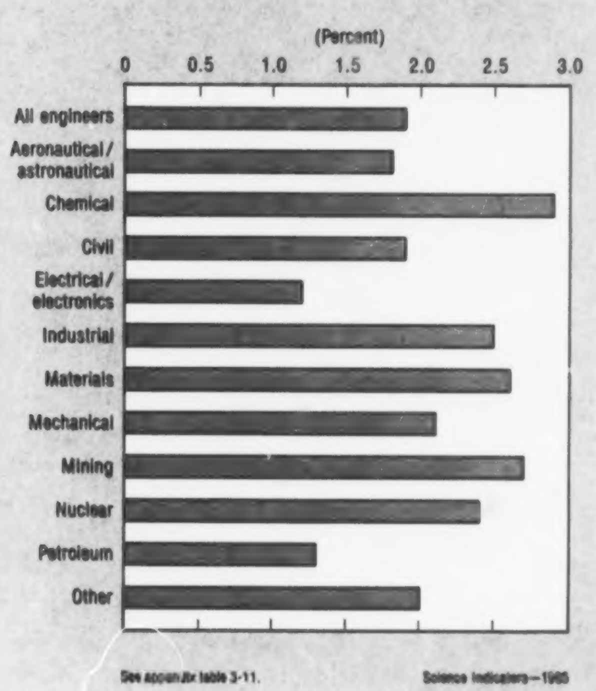
[6]See U.S. Department of Labor (1983).
[7]See U.S. Department of Labor (1983).
[8]See U.S. Department of Labor (1984), p. 167.

Figure 3-12
Unemployment rates of engineers by field: 1983



See appendix table 3-11.

Science Indicators—1985

showed the lowest (89 percent) and nuclear engineers the highest rate (97 percent). Of the 133,900 engineers who did not hold engineering jobs, only about 4 percent did so because they believed engineering jobs were not available. This proportion "involuntarily" in non-S/E jobs varied by field. (See figure 3-13.) Chemical engineers were the most likely to report that an S/E job was not available, while nuclear and petroleum engineers were the least likely.

S/E Underutilization. Although unemployment rates for engineers are relatively low compared with the rates for the general population, those who are employed may be underemployed. Working in a non-S/E job or working part-time may indicate underemployment, depending on the reasons for such employment. To help measure the extent of potential underemployment, the S/E underemployment rate has been developed. This rate shows the number of engineers employed in a non-engineering-related job because they believe a job in engineering is not available, plus the number employed part-time but seeking full-time work, expressed as a percent of total engineering employment.

The underemployment rate for engineers in 1983 was 0.6 percent, with some variation by field. Mining, industrial, and chemical engineers showed rates of about 1 percent, while there was little or no underemployment reported for petroleum and nuclear engineers.

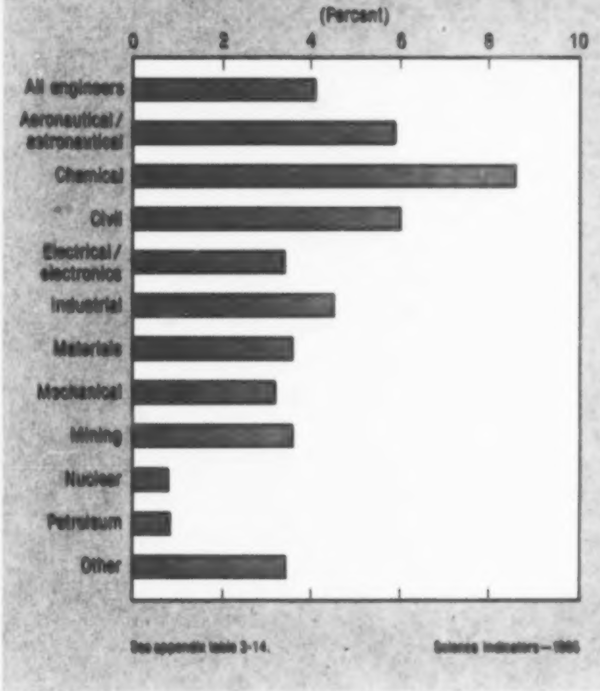
To derive a more comprehensive indicator of underutilization, figures for those who are unemployed and those who are underemployed may be combined and expressed as a percent of the labor force. It is only a partial measure, however, since it does not account for those who may have jobs requiring skills below those that the job holders actually possess.

In 1983, the underutilization rate for engineers was 2.5 percent, with some field variation. The highest underutilization rate was for mining engineers (4.1 percent), while petroleum engineers showed the lowest rate (1.4 percent).

Salary Trend. Relative salaries and salary changes may be indicators of market conditions. In 1982, engineers reported average salaries of $35,700, with substantial variation by field. The highest average annual salary was reported by petroleum engineers ($44,200), while industrial engineers reported the lowest ($32,600). (See figure 3-14.)

Changes in salary offers to new engineering graduates is also a valuable indicator of market conditions. Increases in engineering salary offers to baccalaureate holders ranged from 5 percent to 16 percent between 1981 and 1983.[9] Petroleum engineering continues to command the highest salary offer, with an average yearly offer of about $30,000, 16 percent above the 1981 average. The high salary offers

Figure 3-13
Percent of engineers employed in non-engineering jobs who believed an engineering job was not available by field: 1982



See appendix table 3-14.

Science Indicators—1985

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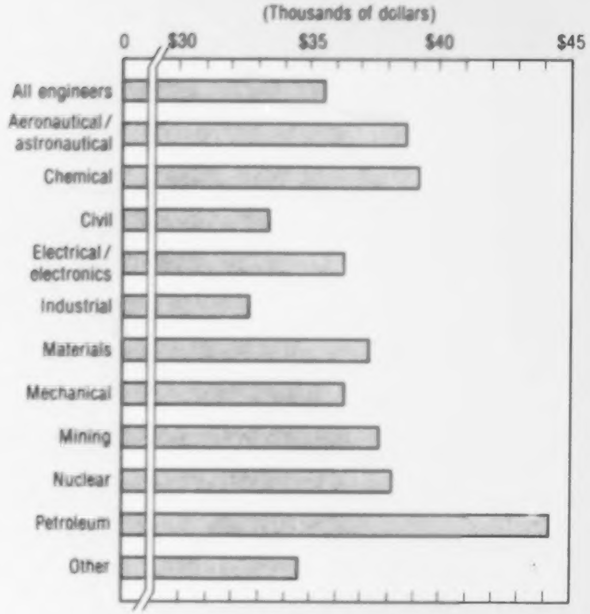
[9] See College Placement Council (1983), p. 2.

Figure 3-14
Average annual salaries of engineers by field: 1982



See appendix table 3-12. Science Indicators—1985

received by bachelor's degree recipients in engineering may effect the propensity of these graduates to enter graduate school. Among those who received engineering degrees in 1980, only about 6 percent were full-time graduate students in 1982. In contrast, among science degree recipients, who generally received lower salary offers, about one-quarter were enrolled as full-time graduate students in 1982.

Engineering—An Historical Perspective

Engineering supply/demand conditions may be better understood if placed in their historical perspective. The engineering profession has undergone recurrent "shortage" and "surplus" conditions for almost four decades. A post-World War II shortage was followed by surpluses in the mid-1950's, and again by shortages following Sputnik. These shortages turned to surpluses following aerospace and defense reductions in the late 1960's and early 1970's. In the early 1980's, another shortage situation evolved.

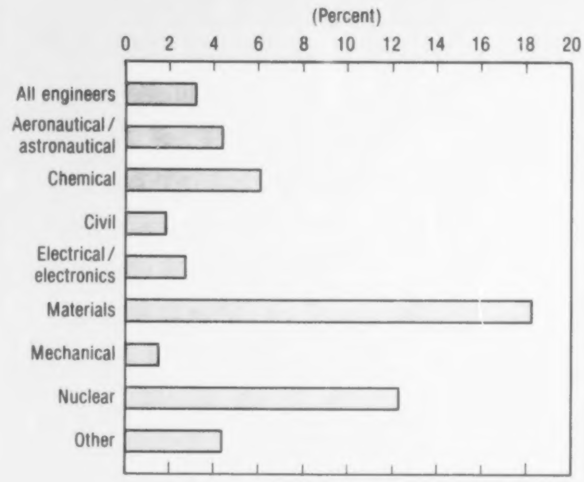
Historical swings in engineering supply/demand conditions have had significant impacts on undergraduate engineering enrollments. The swings in engineering supply/-demand conditions are thought to result from "cobweb" fluctuations in the labor market.[10] That is, a shortage of engineers will induce students to enter undergraduate engineering programs. Four to five years after entering college, however, these students enter the labor market, sometimes causing a surplus of engineers. This surplus—indicated by declining relative salaries and publicized declining job opportunities—results in a drop in new engineering enrollments, thereby sowing the seeds for a future shortage. The relatively large enrollments in engineering schools and the currently large number of students earning degrees in engineering suggests that supply and demand should be in balance for most engineering fields throughout the remainder of the decade.[11]

Doctoral Engineers

Relatively few engineers, compared to scientists, hold the doctorate degree. In 1983, 61,500 engineers held doctorates, representing about 3 percent of all employed engineers (roughly the same proportion as in 1976). Among scientists, about 20 percent held doctorates. Since the mid-1970's, employment of engineers with doctorates has increased at about the same annual rate as overall engineering employment—5.3 percent and 5.1 percent, respectively. In 1983, 91 percent of the doctoral engineers reported that they were working in an engineering or related job, down from 95 percent in 1973. Of those in non-engineering jobs, only a small proportion (6 percent) indicated that they were so employed because they believed engineering or related jobs were not available.

The propensity to hold a doctorate varied considerably by field of engineering. (See figure 3-15.) For example,

Figure 3-15
Percent of employed engineers holding a doctorate: 1983



See appendix table 3-15. Science Indicators—1985

while 3 percent of all engineers held doctorates, 18 percent of the materials engineers and 12 percent of the nuclear engineers held doctorates. At the other end of the spectrum, only about 1.5 percent of all mechanical engineers held the doctorate.

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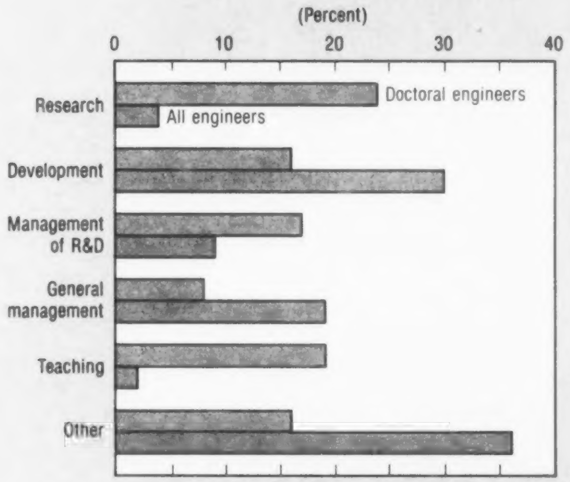
[10] For a brief discussion of the "cobweb cycle" for engineers and a discussion of the "swings" in engineering supply/demand conditions, see Richard Freeman (1976), pp. 112-117.

[11] See NSF (1983).

Engineers with doctorates differed from other engineers in terms of where they were employed and in terms of their primary work activities. Those with doctorates were less likely than other engineers to work in business and industry, and much more likely to be employed by educational institutions. In 1983, 56 percent of those with doctorates worked in industry and 33 percent were in educational institutions (primarily universities and 4-year colleges). In contrast, 80 percent of all engineers worked in business and industry and only 3 percent were in educational institutions. During the 1973-83 decade, employment of doctoral engineers in industry increased at an annual rate of 6.9 percent, while in educational institutions, the increase was 4.6 percent per year. Between 1981 and 1983, however, this long-term trend was reversed. During this period, employment of doctoral engineers in industry increased at an annual rate of 4.2 percent, while in educational institutions, the increase was 6.1 percent per year. Despite this more rapid increase, however, engineering faculty vacancies persist.[12]

The work activities of doctoral engineers differed from those of other engineers, reflecting both differences in sectors of employment as well as activities within the same sector. The greatest difference between doctoral engineers and all engineers was in the proportion reporting teaching as their major activity. Among those with doctorates, 19 percent reported teaching but fewer than 2 percent of all engineers cited teaching as their major activity. Those with doctorates were also more likely to report research and development as their major activity (40 percent versus 34 percent for all engineers). Within research and development, doctoral engineers were much more likely to cite research rather than development as their main area of work (60 percent versus 12 percent). (See figure 3-16.)

Figure 3-16
Primary work activities of doctoral engineers and all engineers: 1983



See appendix tables 3-9 and 3-10. Science Indicators—1985

Women in Engineering

Women were underrepresented among engineers. In 1983, women represented about 3 percent of all employed engineers, but 25 percent of all employed scientists, 44 percent of all employed persons, and 48 percent of those in professional occupations.[13] The underrepresentation of women in engineering persists despite significant employment gains during the 1976-83 period, when employment of women engineers increased by almost 200 percent and employment of male engineers rose by 42 percent. Employment gains for women engineers outpaced gains by women in the general work force. Between 1976 and 1983, employment of women in all occupations increased by 23 percent, compared with about 7 percent for men. Among those in professional occupations, the number of women increased by 30 percent, while employment of men was up 18 percent.[14]

The representation of women among engineers varied considerably by field. (See figure 3-17.) In 1983, about 6 percent of all chemical engineers were women, but only about 1.4 percent of all mechanical engineers were women. While employment of women increased in all major engineering fields, there was substantial variability. Above-average growth for women was recorded for aeronautical and electrical engineers, and below-average growth was noted among civil engineers.

Despite rapid employment gains, women engineers had higher unemployment rates and earned lower annual salaries than their male counterparts. In 1983, the unemployment rate for women engineers was 4.4 percent compared to 1.8 percent for men. Further, the average annual salaries of women engineers were about four-fifths that of men: $29,000 versus $36,000 in 1982 (the latest year for which data are available).[15]

Women's salaries are below those for men across all age groups. However, the differential is lower among younger age groups. For example, among 25 to 29 year olds, salaries of women engineers averaged 98 percent of those for men, while in the 45 to 49 year old age group, women earned only 85 percent of men's salaries. These differences in salary diffentials by age may be explained by a number of factors including the changing career patterns of women.

Minorities in Engineering

Blacks were underrepresented in engineering, while Asians were not underrepresented. Blacks represented 1.8

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[12] NSF, unpublished tabulations.

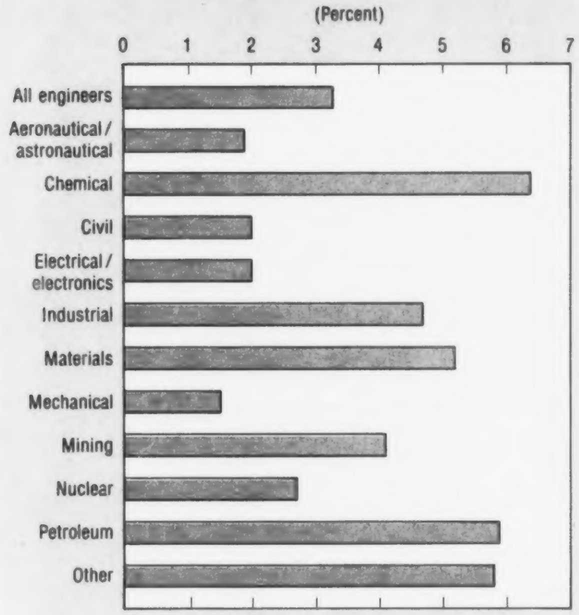
[13] See U.S. Department of Labor (1984), p. 178.

[14] See U.S. Department of Labor (1984), p. 157.

[15] For a more detailed discussion of the labor market experiences of women and minority S/E's, see NSF (1984).

Figure 3-17

Women engineers as a percent of all employed engineers: 1983



See appendix table 3-3. Science Indicators—1985

percent of all employed engineers and 3 percent of all scientists, but 9 percent of all employed persons in the United States and about 9 percent of all employed professionals. In contrast, Asians represented 4.8 percent of all employed engineers, but only 1.6 percent of the total U.S. work force.[16] Native Americans accounted for about 0.5 percent of all engineers, equal to their representation in the U.S. work force.

During the period of 1976-83, employment of black engineers increased almost three times as rapidly as the employment of whites (112 percent versus 40 percent), while the employment of Asians increased half again as rapidly as that of whites (60 percent versus 40 percent).

In 1983, there were over 44,000 Hispanic engineers employed in the United States. This number represented about 2.3 percent of all engineers; almost 7 percent of the U.S. work force was Hispanic in 1983.

Unemployment rates among engineers varied considerably among race and ethnic groups in 1983. Black engineers reported the highest unemployment rate at 4.5 percent, while Asians reported a rate of 3.0 percent. Native Americans had a rate of less than 1 percent, and the rate of Hispanic engineers was 2.0 percent. The comparable rate for white engineers was 1.8 percent. Likewise, there was wide variation in annual salaries among race and ethnic groups. White engineers earned almost $36,000 per year while blacks earned about $32,000. The annual salary of Hispanic engineers was $33,700.

SCIENTISTS

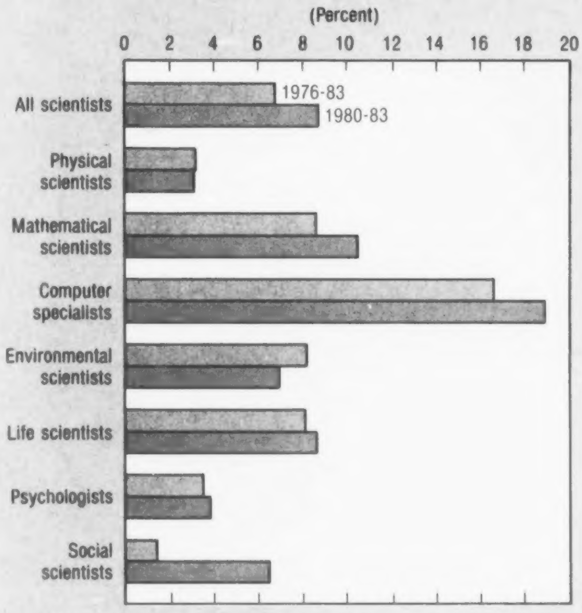
Employment Levels and Trends

Employment of scientists, driven by the rapid growth in computer specialties, has risen faster than that of engineers during the 1976-83 period. In 1983, scientists accounted for 44 percent of all employed scientists and engineers. Over the 7-year period, employment of scientists rose at an annual rate of 8 percent, compared to 5 percent for engineers. Excluding computer specialties, science employment increased at an annual rate of 5 percent. Over the more recent past, 1980-83, the growth rate among scientists, fueled by computer specialists, accelerated while the growth rate among engineers was constant.

There was wide variation in growth across scientific fields. (See figure 3-18.) By far the fastest growing field was computer specialties. Between 1976 and 1983, the annual growth in this field was almost 17 percent—more than double the rate of any other science field. The slowest growing field was the social sciences (1.5 percent per year). Over the more recent past (1980-1983), computer specialities continued as the fastest growing scientific field, while employment in the field of psychology showed the lowest growth (18.9 percent per year for computer specialists and

Figure 3-18

Annual growth rates of employed scientists by field



Based on appendix table 3-3 and unpublished data. Science Indicators—1985

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[16] See U.S. Department of Labor (1984), p. 178.

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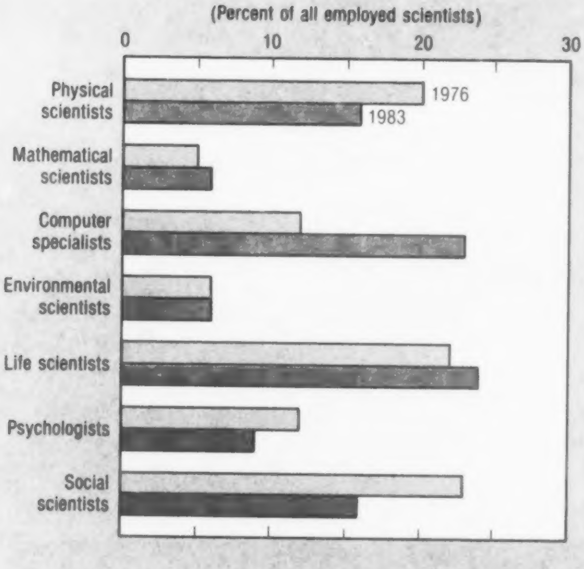
3.9 percent per year for psychologists). In 1983, about one in every four scientists was a computer specialist. (See figure 3-19.)

Computer specialists alone accounted for over 40 percent of the total growth in scientific employment during the 1976-83 period. The large increase in the number of computer specialists (from about 120,000 to almost 350,000) when compared with the relatively small number of individuals earning computer science degrees, raises questions as to the educational background of those employed as computer specialists. This issue may be explored by examining the characteristics of recent S/E graduates.

In 1982, over 20,000 individuals who had graduated with an S/E baccalaureate in 1980 were employed as computer specialists. About 42 percent had earned their degrees in computer science, another 22 percent had earned degrees in mathematics, while 19 percent were granted degrees in either a social science or psychology field. At advanced degree levels, there were also influxes from other S/E fields. At the master's level, 59 percent of the employed computer specialists held degrees in this field. At the doctoral level, however, the proportion was much less: 32 percent held computer science degrees. The largest influx at this level was again from the social science and psychology fields.

Employment in Science Jobs. Not all scientists held jobs specifically related to science. Of the 1.5 million employed scientists, over 1.2 million (82 percent) held jobs in science in 1983. Employment in these jobs has not risen as rapidly as total employment of scientists between 1976 and 1983. The annual growth rate of scientists in science-related jobs was 5.7 percent, still somewhat higher than the 5.1 percent rate for engineers working in engineering jobs.

Figure 3-19
Employed scientists by field



See appendix table 3-3.

Science Indicators—1985

Growth rates varied by field, with computer specialists recording the highest growth rate. Their annual growth over the 7-year period was about 12 percent, followed by environmental scientists at 10 percent, and mathematical scientists at 8 percent. Social scientists in science occupations experienced a declining annual growth rate of less than 1 percent between 1976 and 1983.

Of the 292,700 scientists who did not hold jobs in science, only about 12 percent were so employed because they believed a job in science was not available. The rate of involuntary non-science employment varied by field, ranging from 5 percent of the physical scientists to 20 percent of the life scientists. (See figure 3-20.)

Sector of Employment

Business and industry was the largest employer of scientists, accounting for over one-half (51 percent) in 1983. Educational institutions were second, employing about one-quarter (24 percent) of all scientists, with the Federal Government third, employing about 11 percent.

Industry was the fastest-growing sector of employment for scientists during the 1976-83 period. Over this 7-year time span, employment in this sector grew at an overall rate of 82 percent. This growth was far outpaced by the 218 percent increase in computer specialties. This field accounted for well over one-half (54 percent) of overall science growth in industry; in 1983, computer specialists represented over one-third of all scientists in industry. If this field is excluded from the analysis, the growth rate of scientific employment in industry falls to 46 percent and the proportion of scientists in this sector falls to 43 percent (from 51 percent).

Among science fields, there was wide variation in the proportions of scientists employed in industry. (See figure 3-21.) While nearly four-fifths of the computer specialists were in this sector, only one-third of the life scientists or psychologists were so employed in 1983. Since 1976, the proportions in this sector have increased among all science fields. The largest proportional increases occurred among computer specialists, from 73 percent to 79 percent, and psychologists, from 23 percent to 33 percent.

Within private industry, the largest fraction of scientists (21 percent) were in business services industries in 1982. In comparison, 6 percent of the engineers were concentrated in these industries. The chemicals industry and the finance/insurance/real estate industry each accounted for another 10 percent of all scientists.

Approximately 782,000 scientists worked in educational institutions in 1983.[17] One-third of these scientists were life scientists and another one-third were either social scientists or psychologists. Growth in this sector over the last 7 years has lagged behind total employment growth of scientists: 46 percent versus 59 percent between 1976 and 1983. This slower growth was primarily the result of very slow growth in two fields—the social sciences and psychology. When combined, overall growth in these fields rose only 9 percent between 1976 and 1983. Excluding these two fields, the overall increase in the number of scientists employed in educational institutions was 67 percent.

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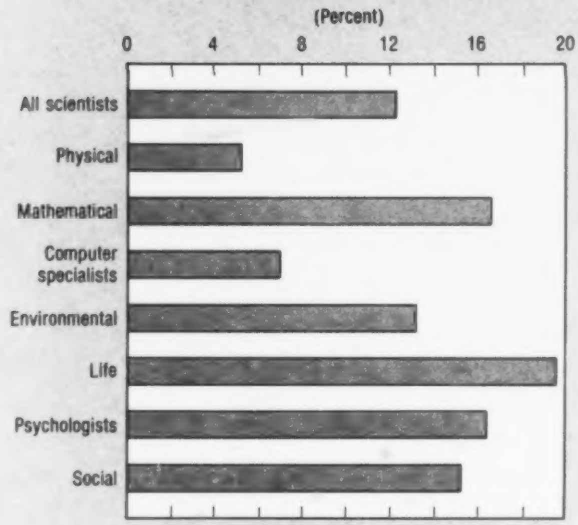
[17] For a more detailed discussion of scientists in academia, see Chapter 5, Academic Science and Engineering.

Character of Scientific Activities

Work activities of scientists have shifted over time. (See figure 3-22.) This shift was primarily the result of the rapid growth of industrially-employed scientists. Activities which were most concentrated in the industrial sector recorded the highest growth rates: development; production/inspection; and reporting, computing, and statistical activities. Between 1976 and 1983, overall growth rates of scientists primarily engaged in these activities ranged from 83 percent (production/inspection) to 262 percent (report/computing/statistical work). Despite these growth rates, research and development—comprising 27 percent of all scientists—continued to be the primary activity of the largest fraction of scientists.

Primary work activities varied considerably among science fields. Work in research and development, excluding R&D management, was the most frequently reported primary activity of physical scientists (45 percent), environmental scientists (44 percent), and life scientists (34 percent). In contrast, over one-half (53 percent) of the computer specialists were primarily engaged in a combination of activities related to reporting, computing, and statistical work.

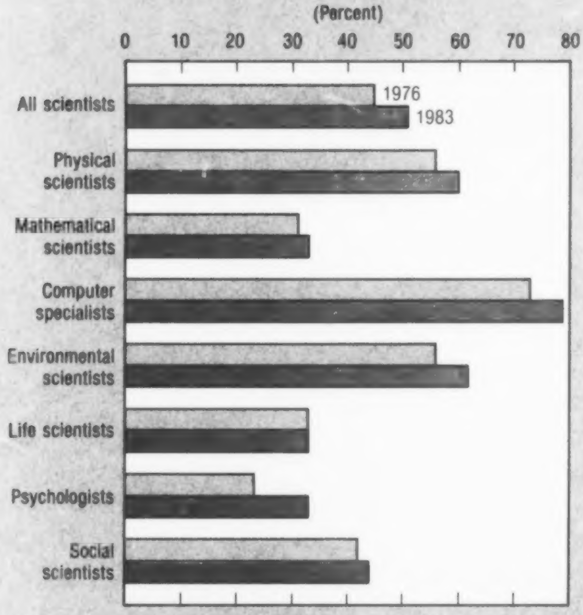
Figure 3-20
Percent of scientists employed in non-science jobs who believed a science job was not available by field: 1982



See appendix table 3-14.

Science Indicators—1985

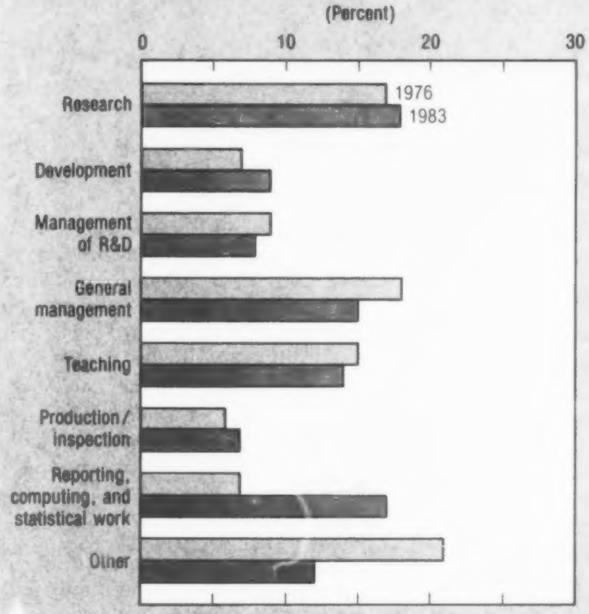
Figure 3-21
Proportion of scientists employed in business and industry by field



See appendix table 3-7.

Science Indicators—1985

Figure 3-22
Primary work activities of employed scientists



Based on appendix table 3-9 and unpublished data.

Science Indicators—1985

Teaching was the activity most often reported by mathematical scientists (37 percent) and psychologists (20 percent). Social scientists reported general management, excluding R&D management (25 percent), more frequently than other primary work activities. Work activity patterns vary considerably by sector of employment. Sectoral analyses of work activities may be found in Chapter 4, "Industrial Science and Technology" and Chapter 5, "Academic Scientists and Engineers."

Scientists by Field of Degree

Not all individuals who are identified as scientists hold their highest degree in science. For example, some may hold a bachelor's or master's degree in a science field but their doctorate in a field such as education. The relationship between a specific science field and a field of highest degree provides an indicator of both market flexibility and supply/demand conditions for scientists. For example, the fact that most chemists hold their highest degree in chemistry would suggest relatively low market flexibility.

About 1.5 million scientists were employed in 1983. Almost 90 percent held their highest degree in a science field; an additional 9 percent held their highest degree outside of science or engineering.

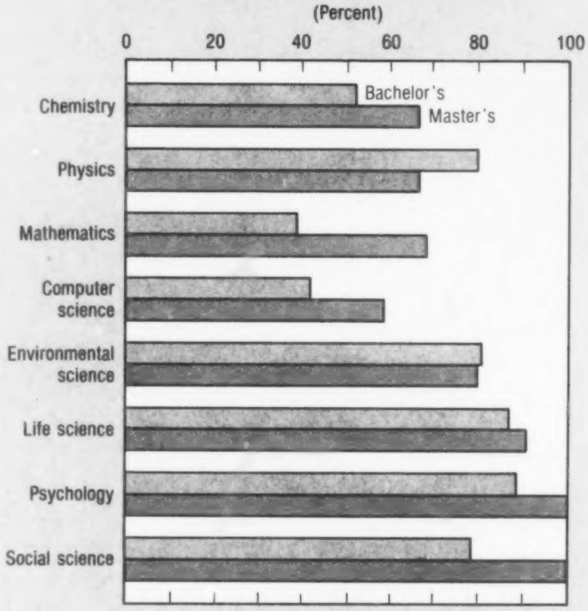
The propensity of scientists to hold a degree coincident with their employment field varied among science fields. For example, while 91 percent of the physicists held their highest degree in physics, only 29 percent of the computer specialists held computer science degrees. Fields with relatively low proportions of highest degree holders in the same field included statistics (59 percent), oceanography (64 percent), and medical science (38 percent). Fields with relatively high proportions included chemistry (82 percent), mathematics (84 percent), psychology (75 percent), and economics (88 percent).

The propensity of recent science graduates to hold degrees in their field of employment may also be an indicator of market flexibility. At the bachelor's level, a substantial fraction of those employed in chemistry, mathematics, or the computer specialties held degrees in other S/E fields. In 1982, for example, about 52 percent of those employed in chemistry had received bachelor's degrees in chemistry in 1980; another 44 percent of those employed as chemists held degrees in the life sciences. In mathematics, while about two-fifths held mathematics baccalaureates, one-quarter had received their degrees in an engineering field. For those employed as computer specialists, many held their degrees in engineering or the social sciences. Among other science fields, most of those employed in a particular field held a degree in that field. (See figure 3-23.) At the master's level, the degree of crossover into other fields was less prominent than at the baccalaureate level. (See figure 3-23.) Computer specialties was one field which experienced notable influxes from other fields, such as engineering and mathematics.

Labor Market Indicators

Labor market indicators are useful in assessing whether or not current supply is sufficient to meet the needs of the economy. In addition to standard labor market indicators, such as labor force participation and unemployment rates, the National Science Foundation has developed the S/E employment rate, the S/E underemployment rate, and the S/E underutilization rate as measures unique to scientists and engineers. No single statistic can provide a basis for measuring surpluses and shortages in particular fields, but some statistics, when examined together, allow inferences about market conditions. The statistics examined below reveal a varied picture for scientists. While a pattern of shortages of computer specialists is evident, there are at least adequate supplies of physical, mathematical, environmental, and life scientists. For social scientists and psychologists, however, indicators show supplies in excess of demand.

Figure 3-23
Proportion of recent science graduates[1] employed in field by degree level



[1] 1980 graduates employed in 1982.

SOURCE: National Science Foundation, *Characteristics of Recent Science/Engineering Graduates: 1982* (NSF 84-318).

Science Indicators—1985

Labor Force Participation. The science labor force includes those who are employed in or out of science, and those who are unemployed but seeking employment. The labor force participation rates measure the fraction of the science population in the labor force.

In 1983, the labor force participation rate for scientists was 95 percent, equal to that for engineers. This rate is significantly above the rates for the general population (76 percent)[18] and for the population completing four or more years of college (87 percent).[19] The rate for scientists has remained stable since 1976.

Labor force participation rates varied little among science fields. The highest rate, about 98 percent, was recorded by computer specialists, while the lowest rate, 94 percent, was registered by both physical and mathematical scientists.

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[18] See U.S. Department of Labor (1984), p. 157.

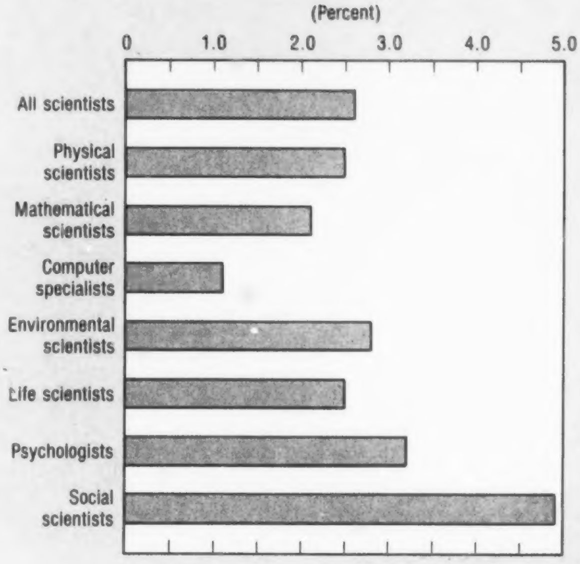
[19] See U.S. Department of Labor (1983).

Of the more than 1.6 million scientists, almost 81,000 were outside the labor force. About two-fifths of those 81,000 scientists were retired, while another one-third cited full-time schooling as their reason for being outside the labor force.[20] About 13 percent of the scientists reported family responsibilities as their primary reason for not being in the labor force.

Unemployment Rates. The unemployment rate measures the proportion of those in the labor force who are not employed but seeking employment. In 1983, scientists registered an unemployment rate of 2.6 percent. This rate was higher than the 1.9 percent rate for engineers but lower than the rates for all professional workers (3.0 percent),[21] for those who have completed four or more years of college (3.5 percent),[22] and for the total U.S. labor force (9.6 percent).[23]

There was wide variation in unemployment rates among science fields. Social scientists experienced the highest unemployment rate in 1983, almost 5 percent, while only 1 percent of the computer specialists were unemployed. (See figure 3-24.)

Figure 3-24
Unemployment rates of scientists by field: 1983



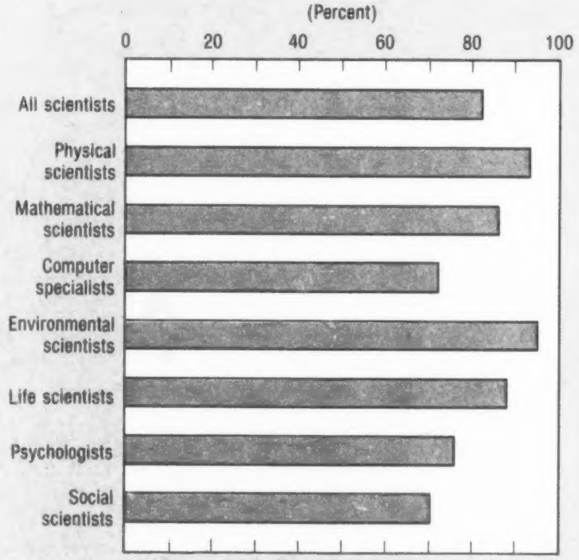
See appendix table 3-11. Science Indicators—1985

The unemployment rate for scientists has decreased since 1976 from 3.7 percent. The rate declined across all science fields with only two exceptions: the rate for environmental scientists rose from 2.1 percent to 2.8 percent, and the rate for social scientists rose from 4.1 percent to 4.9 percent.

S/E Employment Rates. The S/E employment rate measures the extent to which those scientists who are employed hold jobs in science-related work. A low S/E employment rate is a possible indicator of underutilization. Factors related to employment in non-science jobs may include a locational preference, a preference for a job outside of science, or the belief that a job related specifically to science is not available.

In 1983, the S/E employment rate for scientists was about 82 percent, much below that for engineers (93 percent). Rate variation among the science fields was substantial. (See figure 3-25.) Environmental and physical scientists reported rates in the low to mid-90's, while social scientists and computer specialists recorded rates in the low 70's. Since 1976, the S/E employment rate for scientists has fallen across all major fields, except the physical and environmental sciences. The overall science rate has dropped from 88 percent in 1976 to 82 percent in 1983, with the largest decline being reported in the computer specialties: 98 percent to 72 percent. The substantial decline in this field may have resulted partially from the high adaptability of computer training and skills to all occupations and activities.

Figure 3-25
S/E employment rates of scientists by field: 1983



See appendix table 3-11. Science Indicators—1985

S/E Underutilization. While unemployment rates measure that fraction of the science labor force who are not actively utilizing their training skills, they do not capture that fraction of the labor force who are employed but not fully utilizing their skills, i.e., underemployed. Thus an

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[20] National Science Foundation, unpublished tabulations.

[21] U.S. Department of Labor (1984), p. 167.

[22] U.S. Department of Labor (1983).

[23] U.S. Department of Labor (1984), p. 167.

S/E underemployment rate has been developed to help measure the potential underemployment of scientists. It is defined as the number of scientists employed in a non-science job because they believe a job in science is not available, plus the number employed part-time but seeking full-time work, represented as a percent of total employment.

In 1983, the S/E underemployment rate for scientists was 1.9 percent, more than three times the rate for engineers (0.6 percent). Among science fields, the rates varied significantly, ranging from 1.1 percent of the physical scientists to 7.0 percent of the social scientists. The underemployment rate was about 2 percent for mathematical and environmental scientists and computer specialists, while it rose to between 4 percent and 6 percent for psychologists and life scientists.

A more comprehensive indicator of potential underutilization is the S/E underutilization rate. This rate combines the number of scientists who are unemployed with the number who are underemployed, and expresses it as a percent of the science labor force. This rate is still only a partial measure of overall underutilization, as it does not take into account the number of scientists who may have jobs that require skills below their level of training or ability (for example, chemists who may be employed as lab technicians).

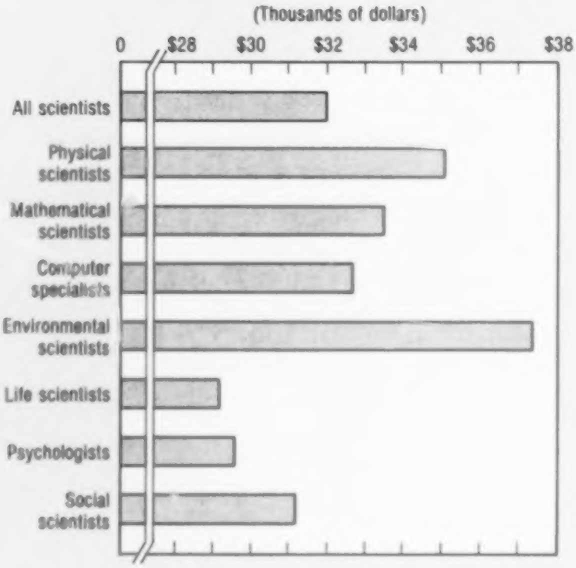
The S/E underutilization rate for scientists was 6.1 percent in 1983; the comparable rate for engineers was 2.5 percent. For most science fields, this rate fell in the 3-4 percent range. However, the rates were much higher for social scientists (11.5 percent), psychologists (9.1 percent), and life scientists (6.2 percent).

Salary Trend. Relative salaries and changes in starting salaries may also be indicators of market conditions. In 1982, the average annual salary reported by scientists was $32,000, compared to $35,700 for engineers. Among science fields, annual salaries ranged from $37,400 for environmental scientists to $29,200 for life scientists. (See figure 3-26.)

Among recent science graduates, this same general pattern in salaries was also evident: natural science graduates, including computer scientists, tended to earn higher annual salaries than life or social science graduates. At the bachelor's level, the range in salaries for 1980 graduates 2 years after graduation was $25,000 (computer science) to $13,000 (psychology). At the master's level, the differential in salaries was equally large: $32,000 (computer science) to $19,600 (life sciences).

Trends in average monthly salary offers to recent degree candidates in science are also indicators of current market conditions. For example, the largest increase in average monthly salary offers to bachelor's degree candidates in science occurred in the computer sciences. Average monthly salary offers to potential computer science graduates rose 73 percent between 1977 and 1983.[24] The lowest increase (49 percent) occurred in the agricultural sciences. In 1983, bachelor's degree candidates in computer science also received the highest average annual salary offer: $23,200. In addition, mathematics and chemistry degree candidates received fairly high salary offers at $21,600 and $20,500, respectively. Life science degree candidates (biological and agricultural sciences) received the lowest offers, about $17,000, among potential science baccalaureate holders in 1983. Similar patterns of average salary offers also exist at advanced degree levels.

Figure 3-26
Average annual salaries of scientists by field: 1982



See appendix table 3-12.

Science Indicators—1985

Doctoral Scientists

In 1983, almost 308,000 employed scientists held doctorates, representing one-fifth of all employed scientists. The comparable rate for engineers was about 3 percent. There was wide field variability in the propensity to hold the doctorate. About one-third of the psychologists, and one-quarter each of the physical, life, and social scientists held doctorates, while only about 4 percent of the computer specialists held such degrees.

Between 1973 and 1983, employment of doctoral scientists rose at a rate of 5.2 percent per year. This rate was somewhat lower than the overall annual growth rate for all scientists (6.9 percent), and slightly lower than that for doctoral engineers (5.6 percent). Annual growth rates varied by field, with computer specialists experiencing the highest annual growth (16.2 percent) and physical scientists recording the lowest rate (2.8 percent.) (See figure 3-27.) Employment increases among doctoral scientists slowed between 1981 and 1983 compared to the 1973-81 period. Between 1973 and 1981, the number of doctoral scientists increased at an annual rate of 5.7 percent; between 1981 and 1983, the annual increase was 3.6 percent. This slowdown in annual growth primarily reflects much slower growth rates in the physical, mathematical, and environmental sciences.

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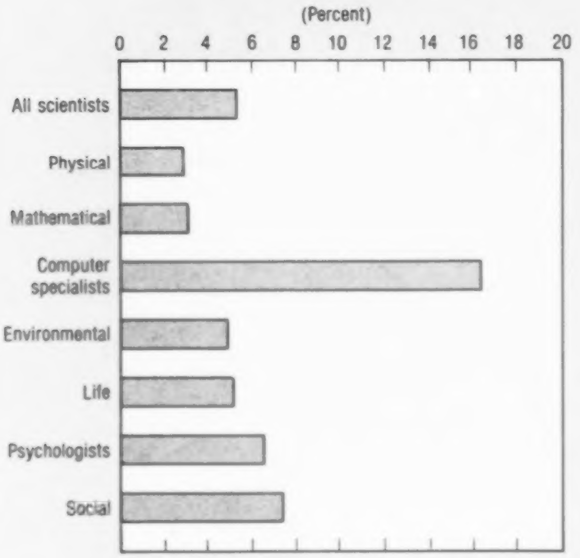
[24] See College Placement Council (1983), p. 2.

Figure 3-27

Annual growth rates of employed doctoral scientists by field: 1973-83



See appendix table 3-6.

Science Indicators—1985

In 1983, about 88 percent of the doctoral scientists were employed in jobs related to science, down from 93 percent in 1973. This S/E employment rate was lower than that for doctoral engineers (91 percent) but much higher than that for all scientists (82 percent) in 1983. About 36,000 doctoral scientists were employed in non-science jobs, but only about 8 percent of those scientists were so employed because they believed a job in science was not available.

The sectoral employment patterns of doctoral scientists differed substantially from those of all scientists. In 1983, most doctoral scientists (57 percent) were employed in educational institutions, and about one-quarter (26 percent) worked in the industrial sector. In comparison, these proportions for all scientists were 24 percent in educational institutions and 51 percent in business/industry. Educational institutions was the sector where most doctoral scientists reported working regardless of field. However, there were two exceptions. Over one-half of the computer specialists were employed in industry and about one-third were in the educational sector; among physical scientists, about the same proportion—45 percent—were in each sector.

While educational institutions continued to employ more doctoral scientists than other sectors, business and industry experienced the highest growth rate among the sectors. Between 1973 and 1983, the annual growth rate for doctoral scientists in industry was 8.3 percent, almost double the 4.2 percent rate in educational institutions. The annual growth rate of 21 percent recorded by computer specialists was primarily responsible for this faster growth in the industrial sector.

The primary work activities of doctoral scientists also differed somewhat from those of all scientists, largely reflecting differences in employment sector. Doctoral scientists reported research and teaching as their primary work much more often than all scientists. In 1983, about 29 percent of the doctoral scientists reported research as their primary activity, and another 31 percent were primarily engaged in teaching. Comparable figures for all scientists were 17 percent (research) and 15 percent (teaching). This pattern of primary work activities differed in only two fields among doctoral scientists. A substantial fraction (32 percent) of the doctoral computer specialists reported development as their primary work; only 12 percent were primarily engaged in research. Among doctoral psychologists, almost two-fifths reported their primary work activity as sales and professional services.

Between 1973 and 1983, development and sales/professional services were the fastest-growing primary work activities among doctoral scientists. The annual rate of growth in development was about 12 percent, while the rate in sales reached almost 14 percent. Among other work activities of doctoral scientists, the annual growth in research was 5 percent, and in teaching, it was 3 percent.[25]

Women in Science

In 1983, women accounted for almost one-quarter of all scientists. This proportion represents a dramatic increase from 1976 when they accounted for only 19 percent of all scientists. However, women are still significantly underrepresented in science compared to all professional workers, where they made up 48 percent.[26] By contrast, in 1983 only 3 percent of all engineers were women. The representation of women across science fields varied considerably. (See figure 3-28.) They were most highly represented among psychologists (41 percent), while their lowest representation was reported among physical scientists (10 percent).

As evidenced by the increased proportion of women scientists in 1983, employment of women outpaced that of men between 1976 and 1983. There were almost 377,000 employed women scientists in 1983, up more than 111 percent from 1976. In comparison, employment of men increased about 47 percent over the 7-year period. This increase in employment of women scientists was higher than that of all employed women (23 percent) and of women in professional occupations (30 percent), but lower than the approximately 200 percent increase between 1976 and 1983 for women engineers. Growth rates for women varied by science field, ranging from about 30 percent for women in the social sciences to almost 400 percent for women in computer specialties. Growth rates for women were higher than those for men among all science fields. (See figure 3-29.)

Women have also made significant employment gains among doctoral scientists. Between 1973 and 1983, employment of doctoral women scientists increased more than three times faster than that of men: 184 percent versus 55 percent. In 1983, the almost 48,000 women scientists with

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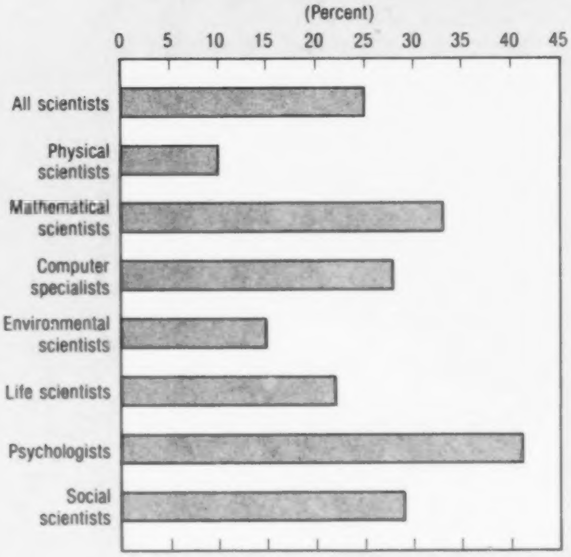
[25] For a more detailed treatment of the work activities of doctoral scientists in industry and academia, see Chapter 4, "Industrial Science and Technology," and Chapter 5, "Academic Science and Engineering."

[26] See U.S. Department of Labor (1984), p. 178.

Figure 3-28

Women scientists as a percent of all employed scientists by field: 1983



See appendix table 3-3

Science Indicators—1985

doctorates represented 15.5 percent of all doctoral scientists, up from 9.1 percent in 1973.

In 1983, the unemployment rate for women scientists was more than double that for men scientists: 4.4 percent versus 2.0 percent. In addition, women scientists earned lower annual salaries. In 1982 (the latest year in which data are available), annual salaries for women ($25,800) were about 78 percent of those for men ($33,200).

Minorities in Science

While employment of black scientists increased dramatically between 1976 and 1983, they still represented only 3 percent of all scientists in 1983. In comparison, they represented fewer than 2 percent of all engineers, but 8.7 percent of all professional workers.[27] Asians accounted for 3.4 percent of all scientists and almost 5 percent of all engineers. However, they represented only about 1.6 percent of the total U.S. workforce.[28] About 7,000 native Americans were scientists in 1983, accounting for about 0.5 percent of all scientists. Native Americans also represented 0.5 percent of the total U.S. work force.

Between 1976 and 1983, employment of black scientists increased at a much faster rate than that of either white or Asian scientists. Their overall growth of more than 120 percent was double that of whites (61 percent) and more than 12 times the rate of Asians (8 percent).

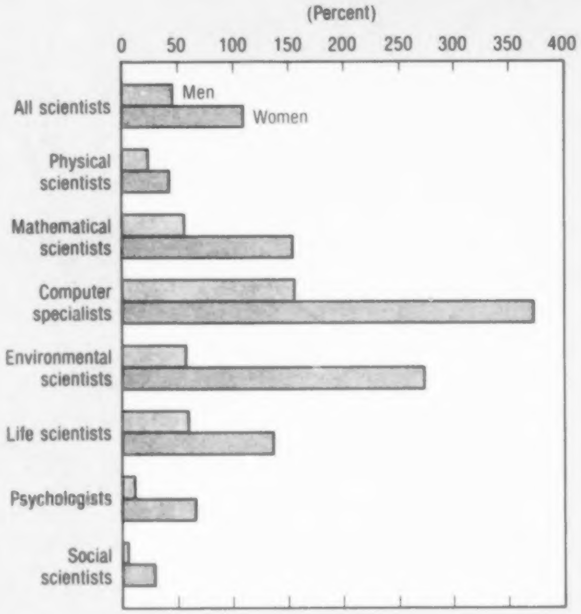
Distributions among science fields varied by racial group. (See table 3-1.) Blacks were much more likely to be scientists than engineers. In 1983, about 57 percent of black S/E's were scientists, compared to 44 percent of whites, 42 percent of native Americans, and 36 percent of Asians.

In 1983, there were over 30,000 employed Hispanic scientists, representing about 2 percent of all employed scientists. In comparison, their representation in the total U.S. work force was 6.9 percent,[29] and 2.5 percent among professional workers.[30] In the science fields, Hispanics were more likely to be social or life scientists and less likely to be environmental or mathematical scientists.

Minority scientists generally experienced higher unemployment rates than white scientists in 1983. While the unemployment rate for whites was 2.5 percent, it was 4.3 percent for blacks, 3.8 percent for Asians, and 3.7 percent for Hispanics. Native American scientists reported a rate of 1 percent. Variation was not as great in average annual salaries reported by race/ethnic group. White, Asian, and native American scientists reported average salaries of about $32,000. Among black and Hispanic scientists, salaries were $28,400 and $27,300, respectively.

Figure 3-29

Growth rates of scientists by sex: 1976-83



See appendix table 3-3

Science Indicators—1985

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[27] U.S. Department of Labor (1984), p. 177.

[28] Data for native Americans and Asians are from U.S. Department of Commerce (1983), p. 7.

[29] See U.S. Department of Labor (1984), p. 202.

[30] See U.S. Department of Labor (1984), p. 178.

Table 3-1. Field distributions of scientists by race: 1983

	White	Black	Asian	Native American
	Percent			
Total scientists	100	100	100	100
Physical scientists	16	8	16	9
Mathematical scientists	6	8	6	1
Computer specialists	23	25	31	19
Environmental scientists	6	1	7	12
Life scientists	25	19	16	22
Psychologists	10	10	3	14
Social scientists	15	29	22	25

See appendix table 3-4.

Science Indicators—1985

OVERVIEW

Employment of scientists and engineers grew more rapidly than total U.S. employment and overall economic activity between 1980 and 1983. This growth is indicative of the increasing importance of science and technology.

Between 1980 and 1983, employment of scientists, fueled by the substantial increase in the employment of computer specialists, increased more rapidly than that of engineers. Computer specialists represent about one-quarter of all scientists, but accounted for two-thirds of overall science growth during the 3-year period.

Employment of engineers grew relatively slower than scientists. This slower increase may have resulted from supply constraints; that is, growth would have been greater had additional engineers been available for employment. Despite the more rapid increase in the employment of scientists, engineers comprised over one-half of the Nation's human resources devoted to science and technology in 1983.

Growth rates varied by science and engineering field during the 1980 to 1983 period. In science, the fastest growing fields were computer specialties, mathematical sciences, and life sciences. The lowest growth rate was in the physical sciences. In engineering, high growth rates were evident in electrical/electronics and aeronautical/astronautical engineering.

Research and development (including R&D management) continued to be the major work activity of the Nation's scientists and engineers, with engineers somewhat more likely than scientists to be involved in some aspect of this work activity. Within research and development, the concentration of S/E's differed. While about four-fifths of the scientists worked in either basic or applied research, the same proportion of engineers were primarily engaged in development.

While involving about 13 percent and 10 percent, respectively, of all scientists and engineers, two of the fastest growing areas of primary work activity between 1980 and 1983 were production and a combination of activities related to reporting, computing, and statistical work. In 1983, engineers were more likely than scientists to be primarily engaged in production activities, including quality control. In contrast, scientists reported the activities related to reporting, computing, and statistical work more often than engineers.

Business and industry continued to be the major sector of employment for scientists and engineers. Between 1980 and 1983, industrial employment of scientists, driven by the rapid increase among computer specialists, rose faster than industrial employment of engineers over this 3-year period. Nonetheless, business and industry employed a larger share of engineers than of scientists: four-fifths versus one-half.

Women and minorities made significant employment gains among scientists and engineers between 1976 and 1983. For example, employment of women rose three times faster than that of men and employment of blacks rose at twice the rate of whites. Despite these gains, women and blacks remained underrepresented among scientists and engineers. In 1983, women represented about 13 percent of all employed S/E's compared to 48 percent of all individuals in professional occupations. Blacks accounted for about 2 percent of all employed S/E's and almost 9 percent of those in professional occupations.

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Chapter 4

Industrial Science and Technology

Industrial Science and Technology

HIGHLIGHTS

- *The health of industrial science and technology has been improving over the past several years.* This is true for both private and Federal spending for industrial R&D, for the hiring of scientists and engineers by industry, for funds available to small high-technology companies, and for the level of interaction of industry with the university sector. Exceptionally high activity is taking place in technologies related to computers and genetic engineering. Small business has continued to be in the forefront in creating technological innovations, as well as new jobs. The decline in patenting by American inventors shows signs of having been reversed.

- *Employment of industrial scientists and engineers continues to climb.* Employment of scientists in industry rose by an average of 8.9 percent per year from 1976 to 1983, while engineering employment rose 6.0 percent per year. This was considerably above the 2.0 percent per year increase for all industrial employment. Growth in science and engineering was led by an increase in the employment of computer specialists, at a rate of almost 18 percent per year. (See p. 76.)

- *Industry employs about four-fifths of all engineers in the United States, and half of all scientists.* Despite the economic recession of the early 1980's, industry has continued to be important as a source of employment for new scientists and engineers and as a site of S/E activity. In 1982, industry hired 59 percent of new bachelor's-level scientists and 80 percent of bachelor's-level engineers, as well as 48 percent of new master's-level scientists and 76 percent of master's-level engineers. At the doctoral level, 22 percent of new scientists and 53 percent of new engineers in 1983 went to industry. At all three degree levels, industry S/E hiring was above the level of the mid- to late 1970's. (See pp. 75-77.)

- *Both private and Federal expenditures for industrial R&D are growing.* Industry is the largest R&D-performing sector in the U.S. economy in terms of expenditures. For 1985, the expenditure (from all funding sources) for industrial R&D was estimated at $77.5 billion, 73 percent of the U.S. total. It rose by 5.3 percent per year, in constant dollars, from 1975 to 1980, but accelerated to 6.0 percent per year from 1980 to 1985. (See p.77.)

- *Private industry has funded more than half of all industrial R&D every year since 1968 and now funds two-thirds of the total.* Growth in this funding was 6.6 percent per year, in constant dollars, from 1975 to 1980. It slowed to 5.5 percent per year from 1980 to 1984 because of the economic slowdown. However, an increase of 6.8 percent is estimated from 1984 to 1985. (See pp. 77-78.)

- *Federal funding supports a third of all industrial R&D.* Particularly large increases in Federally supported R&D are occurring in defense-related areas, such as in the aircraft and missiles industry. In 1985, 87 percent of Federal R&D obligations to industrial performers are from the Defense Department. (See p. 78.)

- *The nonmanufacturing industries that perform R&D had considerable employment growth from 1973 to 1983,* at a time when both high-technology and other manufacturing industries showed no growth. A similar pattern was seen in the shorter interval from 1980 to 1983, but with only slight increases even among nonmanufacturing R&D performers. The generally disproportionate growth in nonmanufacturing employment was due to R&D activities in both manufacturing and nonmanufacturing industries, as well as to the general shift in the U.S. economy toward service industries. (See pp. 78-79.)

- *Decline in U.S. patenting has slowed, with large increases in high-tech areas.* Successful patent applications from U.S. inventors have begun to increase after a long period of decline. Patenting declined by an average of 1.9 percent per year from the peak year in 1969 to the low in 1979. From 1979 to 1984 the pattern, though irregular, showed an overall estimated growth rate of 0.6 percent per year. In contrast, the foreign patenting rate in the United States in those 5 years increased by 4.3 percent per year. (See p. 80.)

- From 1978 to 1984, U.S. patenting in genetic engineering technologies increased by 53 percent per year, far above the change for all technologies combined. Foreign patenting in genetic engineering also increased rapidly (36 percent per year). Other large U.S. increases occurred in robotics (17 percent per year) and digital computer systems. However, U.S. patenting in solar energy has declined considerably. (See p. 82.)

- *Indications of health in high-tech small business.* The venture capital committed to acquiring equity in small high-technology companies has increased considerably in recent years. For high-technology manufacturing, these disbursements grew by a factor of 3 from 1980 to 1983, in current dollars, and another 7-percent increase occurred from 1983 to 1984. In the 1980-83 period, the dollar value of new public offerings of stock in high-technology companies increased by a factor of 12. These large increases were due to improved economic conditions, as well as to changes in relevant tax legislation. (See pp. 83-84.)

- High-technology small firms accounted for only 24 percent of all high-technology employment in 1980. However, they expanded their total employment by 8.3 percent per year from 1976 to 1980, as compared with 3.5 percent per year for the larger high-technology firms. Another indication of the success of small high-technology companies is that in 1982 small companies produced more than twice as many new products per R&D dollar as did all the companies studied. (See p. 84.)

- *Scientists tend to move from academia to industry.* The movement of doctoral-level personnel between academic and industrial employment reflects shifts in the job market. Though it is a small portion of total doctoral employment in those sectors, it represents an important channel for the transfer of information and techniques between them. Between 1981 and 1983, engineers transferred about equally in both directions. However, almost four scientists left academia and went to industry for each scientist who moved in the other direction. The ratio was 7 for life scientists and 6 for social scientists. (See p. 86.)

The industrial sector is the site of most of the research and development (R&D) activity in the United States. Moreover, it is the main source of new technologies that affect the economic and social welfare of the public. Consequently, industry has always figured prominently in public science and technology (S/T) policy.

Current policy interest is centered on sustaining economic growth. This growth depends vitally on continued improvements in industrial technology. Policy interest is also centered on the competitiveness of U.S. industries with regard to their foreign counterparts, in both high- and low-technology areas. Industrial competitiveness affects such broad economic issues as the creation and retention of jobs, the rate of inflation, and the balance of payments. Federal policy seeks to encourage growth and competitiveness in several ways. It seeks to promote technological development through direct support and tax incentives for R&D expenditures, and through measures to control inflation, improve capital formation, and remove unnecessary Federal regulations. Federal support for basic research, principally at universities and colleges, supplies part of the knowledge base for new technology. Support for S/E education provides the necessary personnel, again by way of the university and college sector. Similarly, regulatory and patenting reforms are intended to improve the conditions and incentives for increased S/T activities in industry.

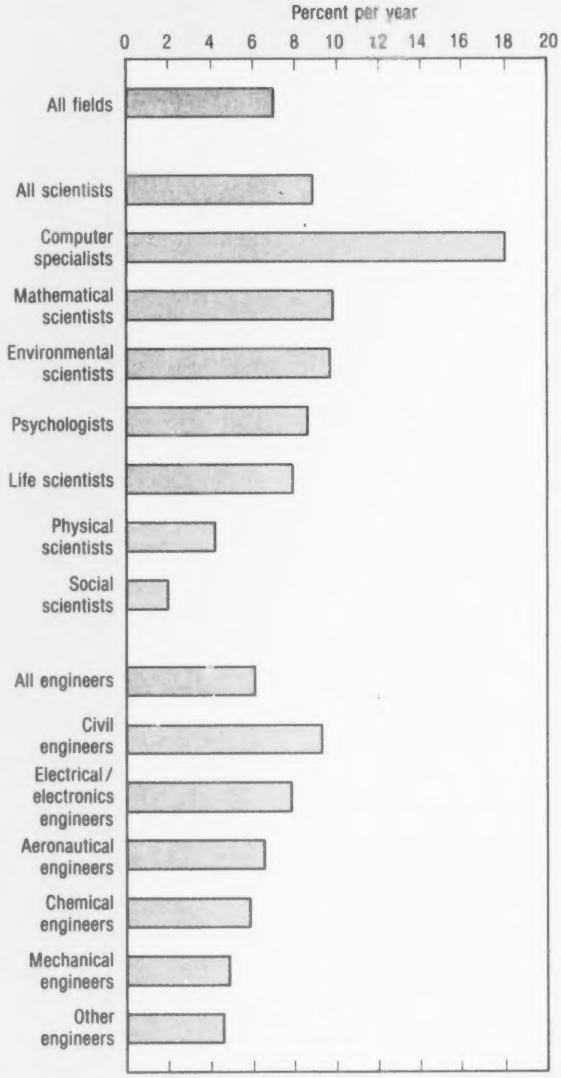
This chapter discusses indicators of recent trends in the S/T resources related to economic growth and improved competitiveness, based on R&D expenditures and S/E personnel. It emphasizes the interactions between the industry and academic sectors, and, where possible, it also presents indicators of technological advances as a result of these S/T efforts.

SCIENTISTS AND ENGINEERS IN INDUSTRY

Few of the resources contributing to industrial science and technology are as important as the technically trained work force. Industry employs about four-fifths of all engineers in the United States, and about half of all scientists.[1] Over three-quarters of all computer specialists are in industry, as are three-fifths of physical scientists and over one-half of all environmental scientists. Within industry, R&D is the primary work activity of about one-fourth of all scientists and engineers. While scientists are concentrated more

Figure 4-1

Average annual growth rate of science and engineering employment in industry, by field: 1976 to 1983



See appendix tables 4-1 and 4-2.

Science Indicators—1985

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[1] See National Science Foundation (1985d), pp. 89-91. These numbers apply to 1983.

in research than in development, the opposite is true for engineers. Many scientists and engineers also engage in other S&T-related activities, such as R&D management, teaching, or production and inspection. (See appendix table 4-2.) Thus, trends in S/E employment in industry are a reflection of shifts in the amount and distribution of S&T-related work going on in industry.

Over the 1976-83 period, total employment in industry rose by 2.0 percent per year, on average.[2] For scientists and engineers in industry, however, the growth rate was 6.9 percent per year. (See figure 4-1.) This suggests not only that employment opportunities are increasing in science and engineering, as compared with other fields, but also that industry itself is becoming more and more reliant on science and technology to improve its products and production processes.

In 1983, industry employed over 780,000 scientists and 1,550,000 engineers (appendix table 4-2). Employment of scientists was dominated by computer specialists, while electrical/electronics and mechanical engineers were dominant among engineers. Figure 4-1 shows the trends in the industrial employment of scientists and engineers since 1976. Clearly the outstanding group in terms of rate of growth was the computer specialists, who accounted for more than half of total employment growth in the sciences and, by 1983, made up 35 percent of all scientists in industry. Mathematical scientists, many of whom work in computer-related areas, were the second most rapidly increasing group.[3] Demand for computer engineers, as well as electrical engineers, was projected to be high for the 1984-85 recruiting year.[4] Demand for chemical, electronics, mechanical, nuclear, and petroleum engineers, and for computer scientists and systems analysts, was expected to be moderate.

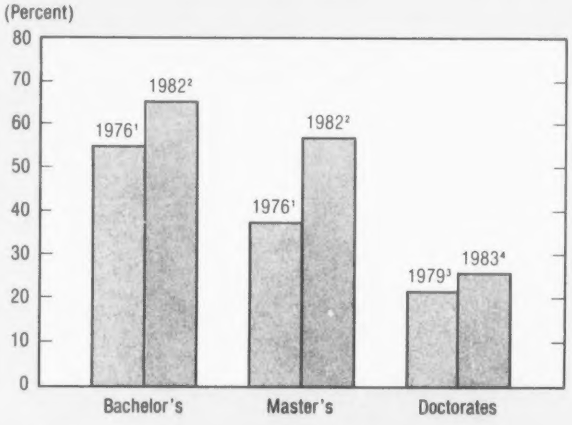
Recent Science and Engineering Graduates in Industry

In recent years, industry has become increasingly important as an employer of graduating scientists and engineers. In part, this is because of a decline in the opportunities available in academia and in Government laboratories. Therefore, new graduates must think more seriously than in the past about careers in industry. Industry's hiring of new S/E's has increased in spite of the recession in 1982 and 1983. Without the recession, hiring presumably would have been even higher in those years.

For example, in 1982 there were 391,000 employed persons who had received bachelor's degrees in science or engineering in the preceding two years. Of these, 65 percent were employed in business and industry. (See figure 4-2.) In 1976, there were more employed bachelor's graduates who had received their degrees in the preceding two years, but only 55 percent of them were in business and industry. The overall result was a 14-percent increase in new bachelor's degree recipients in industry in 1982 as compared with 1976. (See appendix table 4-3.) New graduate scientists in industry greatly outnumbered new graduate engineers in both 1976 and 1982. Within the sciences, computer specialists showed the greatest growth.[5] (See appendix tables 4-1 and 4-2.) Without the computer scientists, there would have been a drop in new bachelor's level scientists between 1976 and 1982. Within engineering, electrical and electronic engineers and mechanical engineers were hired in the greatest numbers.[6]

Figure 4-2

Proportion of recent science and engineering degree recipients finding employment in industry, by degree level



[1]1974 & 75 graduates.
[2]1980 & 81 graduates.
[3]1977 & 78 graduates.
[4]1981 & 82 graduates.
See appendix table 4-3.

Science Indicators—1985

At the master's degree level, 65,000 persons received S/E degrees in 1980 or 1981 and were employed in 1982. Again, this represents a drop from the number of new graduates employed in 1976. However, the number of such graduates employed in business and industry increased 22 percent between 1976 and 1982. Only 38 percent were in business and industry in 1976, as compared with 57 percent in 1982. In 1982, industry had hired more new masters' level scientists than new engineers, although this was not true in 1976. Again, computer specialists accounted for the greatest growth among industry scientists, though new social scientists also increased significantly. The number of new engineers in industry at the master's level actually declined from 1976 to 1982.

The doctoral level has the smallest number of new graduates. Of the 35,000 who graduated in 1981 or 1982 and were employed in 1983, 27 percent were in industry. In 1979, there were fewer doctoral-level employed graduates from the preceding two years, and 22 percent were in industry. The net result was a 31-percent increase from 1979 to 1983 in new S/E doctorate holders in business and industry. Scientists were again more numerous than engineers at this degree level. The greatest increase was among Ph.D. psychologists, though significant increases also occurred among social scientists and life scientists.

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[2] See Bureau Labor Statistics (1984), table B-1. This figure applies to all private industry.

[3] The section of this chapter on small business points out that a very large share of venture capital support is going to computer-related small firms.

[4] See National Science Foundation (1985e).

[5] This was also the group of scientists that most increased its number employed in industry, according to figure 4-1.

[6] Appendix table 4-2 shows that these are also the largest groups of engineers employed in industry.

EXPENDITURES FOR RESEARCH AND DEVELOPMENT IN U.S. INDUSTRY

Trends in the constant-dollar funds spent on R&D in industry can be interpreted as trends in the level of R&D activity in industry. Less directly, these funding trends also represent changes in the efforts devoted to technological innovation. R&D funds in industry come almost exclusively from two sources: private industry itself and the Federal Government.[7] Total current-dollar expenditures for industrial R&D have increased markedly in the last several years, with $69.3 billion estimated for 1984 and $77.5 billion for 1985.[8] (See figure 4-3.) If these estimates are borne out, the growth rate from 1980 to 1985 will be 12 percent per year in current dollars. In constant-dollar terms, total R&D funding in industry has risen every year from 1975 to 1985 at an average rate of 5.7 percent per year, and has grown 6.0 percent per year in the last few years, 1980-85.

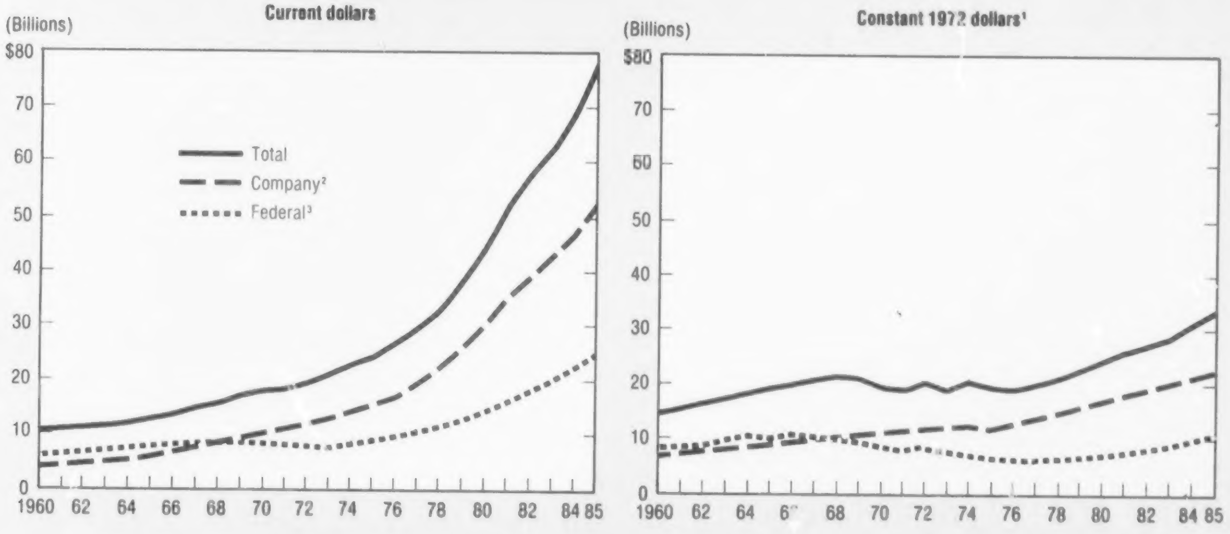
Since total R&D funding in the United States will be on the order of $106.6 billion in 1985, industry, by this measure, performs 73 percent of the Nation's R&D.[9] About 77 percent of industrial R&D funding is for development,[10] while development is only 33 percent of R&D expenditures in all other sectors combined.

Trends in Company Funding

The component of industrial R&D funded by private sources is especially significant. Much of the Government's policy with respect to industrial technology, including efforts

Figure 4-3

Expenditures for industrial R&D by source of funds



[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
[2] Includes all sources other than the Federal Government.
[3] Includes Federally Funded Research and Development Centers administered by industry.
Note: Preliminary data are shown for 1983 and estimates for 1984 and 1985.
See appendix table 4-4.

Science Indicators—1985

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[7] The small amount of funding from other sources, such as State Governments, is combined with private company funding in the following discussion.

[8] By contrast, Battelle estimates total industrial R&D expenditures in 1984 to be $72.0 billion ($23.35 billion from Federal sources) and $79.95 billion in 1985 ($25.77 billion from Federal sources). See Battelle (1984) p.5.

[9] See appendix table 2-2. By comparison, industry performed 71 percent of R&D in the United States in 1965, and 69 percent in 1975. See National Science Foundation (1984b), p. 28.

[10] This figure is an estimate for 1984. See National Science Foundation (1984b), pp. 28,31.

to stimulate the economy, special tax credits for R&D, and relaxing of the restrictions on R&D consortia involving competing industrial companies, is directed to encouraging this private investment. In particular, the Economic Recovery Tax Act of 1981 provided a 25 percent tax credit for incremental R&D expenditures made between July 1, 1981 and December 31, 1985. More recently, the National Cooperative Research Act was passed in October 1984, to encourage cooperative research ventures by private companies. State governments have also been active in encouraging high-technology investments by private companies.[11]

Trends in company-originated funding can be seen in figure 4-3. In 1985, company funding was estimated to be 68 percent of all R&D expenditures in industry. The share of total industrial R&D outlays provided by industry first exceeded the share provided by the Government in 1968, and increased throughout the 1970's.[12] From 1975 to 1984, the annual rate of increase in company R&D spending was 6.2 percent per year, in constant-dollar terms. In addition, a 7-percent increase is estimated from 1984 to 1985.

A variety of factors has contributed to the high rate of private investment in R&D. For example, officials from about one-third of a group of large R&D-performing companies reported in 1984 that the Economic Recovery Tax Act had favorably influenced their R&D budgets.[13] Moreover, there was no decrease in constant-dollar company R&D expenditures during the recession in the early 1980's, as there was in the recession years of 1970-71 and 1975. This in itself may imply that the Act had a positive effect. Companies are also increasing their commitment to R&D because of concern that foreign competition is steadily eroding the U.S. technological lead.[14] A recent study indicates that R&D contributed significantly to industrial productivity in both the 1960's and 1970's. Basic research appeared to make an especially large contribution. Federally financed R&D expenditures had a positive effect on productivity, but private support contributed significantly more.[15]

Trends in Federal Funding

While constant-dollar company funding for R&D has shown an almost uninterrupted increase, Federal funding has shown far greater variations. Its historic high was in 1966, after which declines in many programs, particularly NASA, led to a steady overall decline that lasted until 1975. Since 1975, however, Federal constant-dollar expenditures for industrial R&D have increased at an average annual rate estimated at 4.5 percent per year, through 1985. The recent increase in emphasis on defense-related R&D has brought the Federal contribution, in constant dollars, back to the levels of the 1960's. For example, in Fiscal Year 1985 the Department of Defense is contributing an estimated 87 percent of all Federal funding obligations for industrial R&D.[16] By contrast, in Fiscal Year 1980, the Defense Department accounted for only 70 percent of Federal obligations for R&D in industry.[17] In addition to defense, the Government's policy is to increase support for civilian-oriented basic research, while giving considerably less emphasis to applied research or development projects.[18] For example, from 1980 to 1985 Federal obligations for industrial applied research and development from agencies other than the Defense Department dropped from $5.0 billion to an estimated $4.2 billion.[19]

R&D Expenditures in Individual Industries

Trends in R&D expenditures are naturally quite different from one industry to another. As shown in figure 4-4, industries may be divided into three general groups: high-technology manufacturing, other manufacturing, and nonmanufacturing.[20] This division is in accordance with current policy interest in high technology, and also reflects the distinction between manufactured goods and services.

It is not surprising that high-technology manufacturing industries accounted for 76 percent of total R&D funding in 1983. The other manufacturing industries accounted for 21 percent, while nonmanufacturing (including services) accounted for only 3 percent. By comparison, only 42 percent of total employment in R&D-performing companies was in high-technology manufacturing, while 45 percent was in other manufacturing, and 13 percent in nonmanufacturing.[21] (See figure 4-5.) Similarly, high-technology manufacturing had a lower share of net sales than of R&D expenditures in 1983.[22]

During the 10-year period from 1973 to 1983, the average growth rate of R&D expenditures in all three sectors was roughly the same, at 4.1 percent per year in high technology, 2.8 percent in other manufacturing, and 3.6 percent in nonmanufacturing, in constant-dollar terms. During this interval, the growth rate in total employment was negative in high-technology manufacturing[23] and in other manufacturing, but exceedingly large in R&D-performing nonmanufacturing (13.1 percent per year). This is a clear reflection of the shift in U.S. industry from goods to services.[24]

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[11] See Office of Technology Assessment (1984), and National Governors' Association (1983). Trends in collective industrial research in the United States and some other countries are studied in Haklisch (1984).

[12] Trends can be followed since 1960.

[13] See National Science Foundation (1984d).

[14] *Business Week* (1984). This reference contains a listing of the companies with the greatest R&D expenditures.

[15] See Griliches (1985).

[16] See National Science Foundation (1985f).

[17] See National Science Foundation (1984f), p. 33.

[18] See Keyworth (1984).

[19] See National Science Foundation (1985f), pp. 309,326,361,378. The estimate for 1986 is $4.3 billion.

[20] A list of the industries in each group is shown in appendix table 4-5.

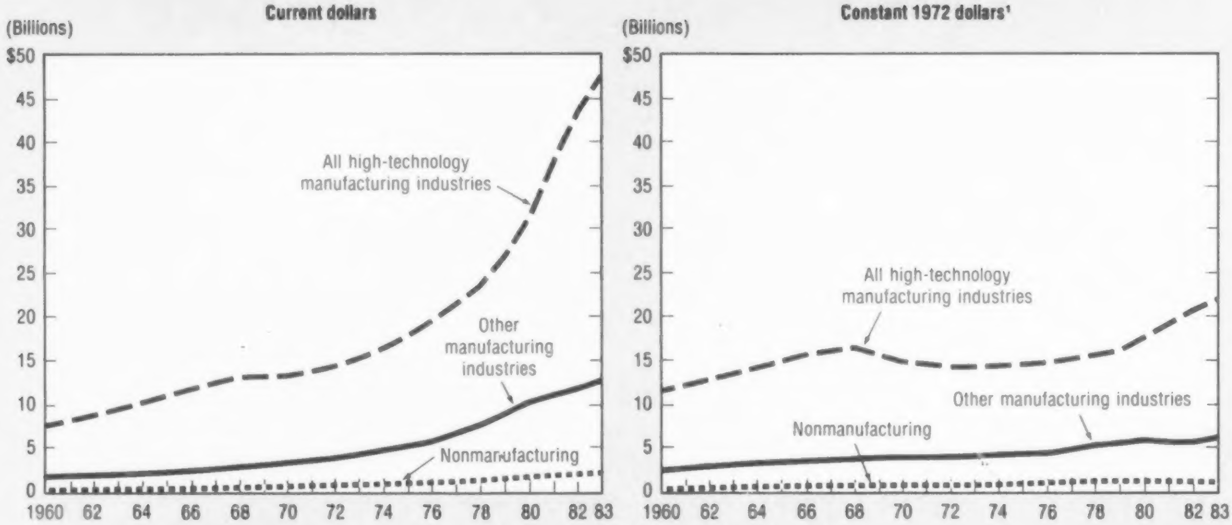
[21] It is important to note that the nonmanufacturing employment and sales figures discussed here apply only to those nonmanufacturing industries that report R&D expenditures, not to *all* nonmanufacturing industries.

[22] The figures are: 33 percent of net sales in high-technology manufacturing, 54 percent in other manufacturing, and 13 percent in R&D-performing nonmanufacturing. (See appendix table 4-7 and National Science Foundation (1985b).)

[23] For 1973 data, see National Science Foundation (1976), p. 52 and National Science Foundation (1984c), p. 10. Recent studies of the effect of technology on employment include Leontief and Duchin (1983), Business-Higher Education Forum (1984), and National Academy of Engineering (1983).

[24] More than half of the R&D expenditure and employment in this nonmanufacturing sector is in electric, gas, and sanitary services; computer and data processing services; miscellaneous business services (which include computer programming and other software, R&D laboratories, and commercial testing laboratories); and engineering, architectural, and surveying services.

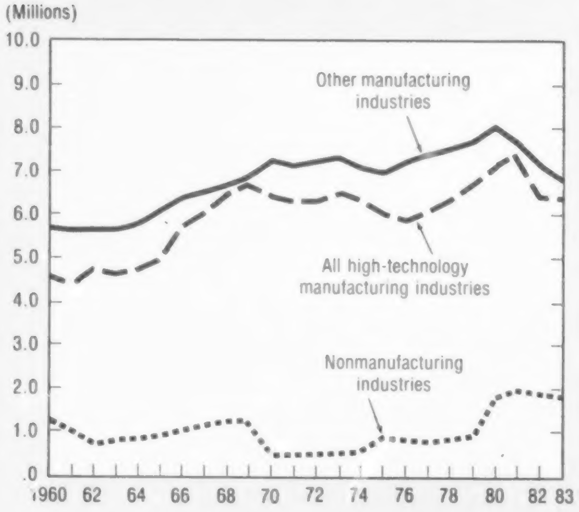
Figure 4-4
R&D expenditures, by industry group



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.
NOTE: Data include Federally Funded Research and Development Centers administered by industry.
See appendix table 4-5.

Science Indicators—1985

Figure 4-5
Total employment of R&D-performing companies, by industry



See appendix table 4-6.

Science Indicators—1985

A somewhat different pattern has occurred in the shorter interval from 1980 to 1983. This was partly a period of economic slowdown, with constant-dollar net sales declining in all three sectors combined, and particularly in non-high technology manufacturing.[25] At the same time, R&D outlays in high-technology manufacturing went up considerably, at a rate of 7.2 percent per year, in constant dollars. This is far above the rise in other manufacturing (0.8 percent per year) and the 1.9 percent per year decline in nonmanufacturing. During the same period, employment declined in both high-technology and other manufacturing (at rates of 4.1 percent and 5.3 percent per year, respectively). In nonmanufacturing there was an increase in employment (0.2 percent per year), in spite of the economic decline. Thus, in this shorter interval there was an especially high growth in R&D in high-technology manufacturing. While employment in R&D-performing nonmanufacturing did not grow as fast as in the whole 10-year interval, there still was some increase.

The increase from 1980 to 1983 in high-technology manufacturing R&D was largely due to the aircraft and missiles industry: Federal R&D expenditures in this industry grew by about 30 percent in constant dollars. In dollar terms,

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[25] The rates were -2.0 percent per year overall, 0.5 percent per year in high-technology manufacturing, -4.2 percent per year in other manufacturing, and 1.7 percent per year in nonmanufacturing.

Federal support accounts for most of this industry's R&D growth.[26] Another large increase—almost 33 percent, in constant dollars, from 1980 to 1983—was in private R&D expenditures in the chemicals industry. The Federal component of R&D support to various industries is shown in appendix table 4-19. In addition to aircraft and missiles, large percentage increases in Federal support since 1980 have occurred in primary metals and nonelectrical machinery, including computers.[27]

PATENTED INVENTIONS

Industrial R&D produces many benefits for the performing company, among them a stream of new technical inventions that may eventually be embodied in new or improved products, processes, and services. Inventions cannot be directly counted or measured, but the patents taken out on new inventions can be counted. Numbers of patents can therefore serve as a surrogate for numbers of inventions themselves. This procedure, of course, has obvious difficulties. Since not all inventions are patented, the assumption is implicitly being made that the patented inventions are representative of the totality of inventions. More specifically, the assumption is that patented inventions are the same share of total inventions for every year, country of origin, owner, or field of technology that is being compared.[28]

The second difficulty is that patents, like inventions themselves, are not equally significant. This is true whether significance is construed in technical or in economic terms. However, counts of patents, like counts of anything else, implicitly treat all the counted entities as equal.[29]

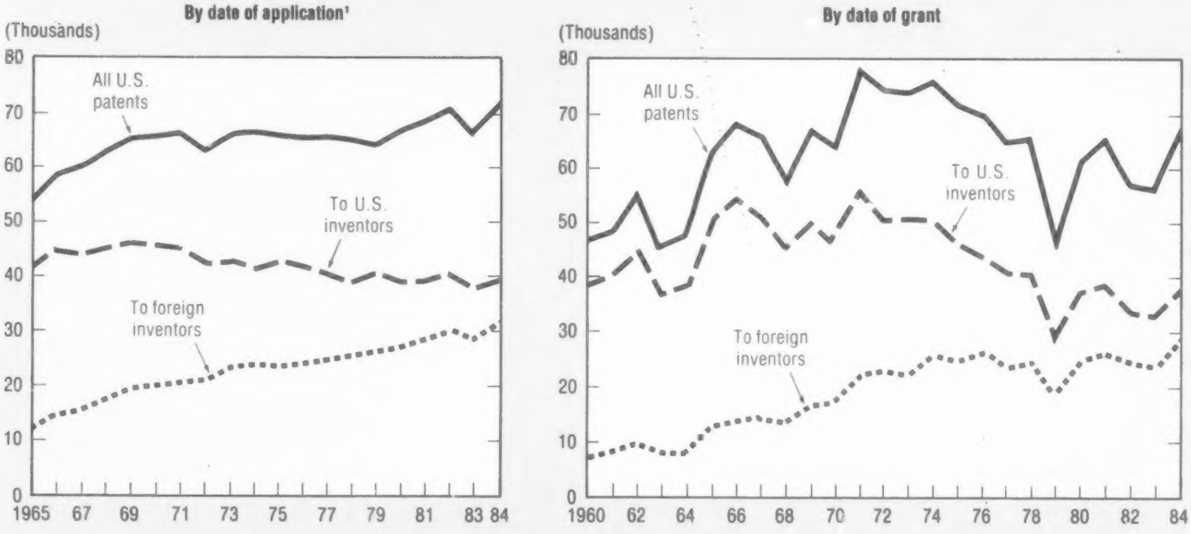
Ideally, each patent would be weighted for its relative significance before being counted. While some methods for doing this have recently been developed, they have not yet been extensively tested.[30] In spite of these problems, patent counts are a unique source of information on trends in technical invention.[31]

Inventors and Owners of Inventions Patented in the United States

The U.S. Patent and Trademark Office issues patents to both American and foreign inventors. Figure 4-6 shows the annual number of patent grants to both classes of inventors, as well as the total number granted. One of the plots shows the years in which patents were granted and the other the years in which granted patents were applied

Figure 4-6

U.S. patents granted, by nationality of inventor



[1] Estimates are shown for 1980-84 for patenting by date of application.

See appendix table 4-8.

Science Indicators—1985

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[26] In 1983, the Federal Government paid for 75 percent of the R&D expenditures in this industry. Aircraft and missiles companies received 51 percent of all Federal R&D support to industry, and accounted for 8 percent of all private support. See National Science Foundation (1985b).

[27] For a discussion of Federal and private R&D support in individual industries, see National Science Foundation (1985c).

[28] Since various industries may differ significantly in the fraction of inventions that they patent, comparison of the patenting rates between industries is probably inadvisable.

[29] Strictly, the assumption is that the distribution in terms of significance is the same for all groups of patents that are compared.

[30] Such methods are based on the payment of renewal fees, the frequency of citation by later patents, or the extent of patenting the same invention in foreign countries. A recent study of this type is Schankerman and Pakes (1985).

[31] A good review of current knowledge in this field is Pavitt (1985).

for. In terms of the year of grant, there has been a general decline in the patents granted to U.S. inventors since the peak in 1971. Foreign patenting in the United States has generally increased over the period shown on the figure, though the year-to-year trends are quite irregular. Year-to-year irregularities in the data are due more to the unevenness of the processing of grant applications by the Patent Office than to any irregularity in the production of inventions.

For this reason, figure 4-6 also shows the same granted patents in terms of the years in which they were applied for. The year of application is roughly 2 or 3 years before the year of grant. Since it does not include the processing time in the Patent Office, it is closer to the time in which the invention actually took place.[32] In terms of the date of application, foreign patenting in the United States shows a steady increase, with dips only in 1975 and 1983. From 1974 to 1984, the rate of increase averaged 2.8 percent per year. Patenting by U.S. inventors has shown a more complicated trend, peaking in 1969, and generally declining by an average of 1.9 percent per year up to 1979. From 1979 to 1984, the pattern was irregular, but there was an overall increase of 0.6 percent per year.

Since patent counts are not the same as total counts of inventions, these trends are not always reflections of trends in the number of inventions produced. In particular, trends in foreign patenting are influenced by the desire of companies in the patenting countries to sell their products in the United States. However, the longer-range decline in U.S. domestic patenting from 1969 to 1979 seems to be a genuine reflection of a decline in the production of inventions.[33] Since the pattern since 1979 shows no clear overall trend, more time will be needed to decide whether the decline has been reversed.

Figure 4-7 divides the patents of U.S. inventors according to their class of owner. Inventors who work for private corporations or for the Government commonly assign ownership of their patents to their employer, while self-employed inventors usually do not assign their patents. Thus, the sector of the owner is a good approximation to the sector

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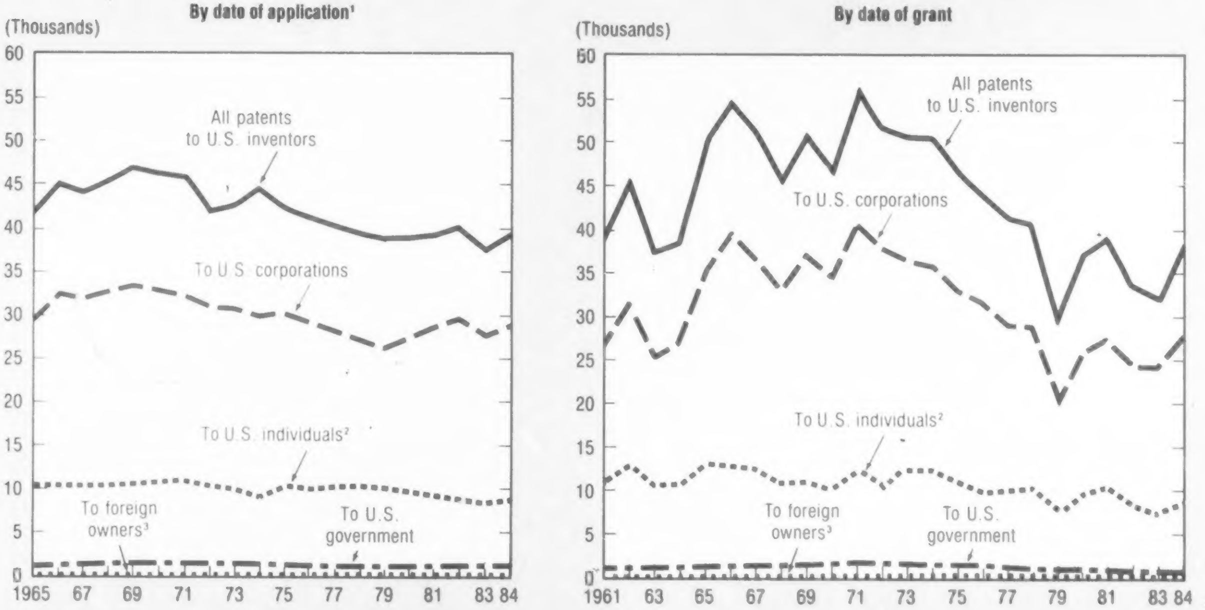
[32] This way of presenting the data has a disadvantage, in that the patent applications filed in recent years have not all been processed, so that one does not know how many will eventually result in grants. Consequently, estimates have been made for recent years, based on the total number of applications and an average annual rate of success in the recent past.

[33] This argument is strengthened by considering the broad range of product fields involved in the decline from 1969 to 1979. On the other hand, some experts argue that there has been an increased use of nonpatented trade secrets, partly because many technologies are changing so fast that the risk of disclosure through a patent application outweighs the benefit of long-term patent protection. This would be the case especially with process inventions and electronics technologies. See Pavitt (1985).

Figure 4-7

U.S. patents granted to U.S. inventors, by type of owner



¹Estimates are shown for 1980-84 for patenting by date of application.

²Includes unassigned patents.

³Comprises patents assigned to foreign corporations, governments, and individuals.

See appendix table 4-9.

Science Indicators—1985

in which the inventive work was done.[34] The figure shows that most U.S. patents are assigned to corporations—70 percent of the total in recent years. Thus, trends in patenting by U.S. inventors are due mainly to trends in corporate patenting. In terms of application dates, the peak year for corporate patenting was 1969. There was a 20-percent drop from that year to the low year of 1979. In contrast, patenting by individual owners (about 26 percent of the total) has oscillated, with peak years in 1971 and 1976. Since 1976, estimates are that successful applications by individuals have declined rather steadily.

Patenting in Individual Technology Fields

In addition to overall patenting trends, trends in patenting in key individual technologies are important, since such technologies have a technical or economic significance of their own. Thus, table 4-1 lists a set of technological fields that are important for different reasons. For example, genetic engineering, robotics, and light-wave communications are relatively new and rapidly developing "high-tech" fields. On the other hand, iron and steel, internal combustion engines (an important component of the automotive industry), and jet engines represent older industries in which the United States may be losing its competitive edge. Two energy fields are considered because of the policy interest of energy, particularly in the 1970's. The table shows annual growth rates in these fields, over the past 6-year and 10-year periods, for both U.S. and foreign inventors.[35]

Genetic engineering is clearly a very rapidly growing field, with substantial increases in both U.S. and foreign patenting. For the 1974-84 period the growth rate was substantial, but less than the 1978-84 growth rate, which shows that activity has accelerated in the last 6 years. The same is true for robotics and digital computer systems, except that the growth rates are less and the foreign growth rate is very close to that for U.S. inventors. Telecommunications, internal combustion engines, semiconductors, and light-wave communications show growth over the 6-year period, while overall patenting was declining. Foreign patenting in these fields rose faster than American patenting, however. In the energy fields, nuclear energy patenting by U.S. inventors has been below the average for all technologies. Solar energy patenting increased quite rapidly over the 10-year period, but the component due to U.S. inventors has slackened in recent years.

SMALL BUSINESS AND TECHNOLOGICAL PROGRESS

Small business is widely regarded as a particularly important segment of U.S. industry because it is believed to

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[34] Inventions achieved in universities either remain the property of the individual inventors or are assigned to the university. Patents assigned to universities are counted in this chapter as corporate-owned patents. They make up only a very small fraction of all corporate-owned patents. They are discussed separately in Chapter 5, "Academic Science and Engineering."

[35] The table shows patents granted by the U.S. Patent Office. It is more meaningful to compare growth rates of U.S. and foreign patenting than to compare simple patent counts. Growth (or decline) rates are calculated by fitting a least-squares line to the logarithms of the patent counts for each year. This procedure would produce a perfect correlation for an exponentially growing field.

Table 4-1. Rate of change in patenting in the United States in various technologies, by date of patent grant

Technology	1978-83		1973-83	
	U.S.[1]	Foreign[1]	U.S.[1]	Foreign[1]
	Percent increase or decrease per year			
All technologies	−2	2	−4	0
Genetic engineering	66	50	40	21
Robotics	14	15	7	9
Digital computer systems	6	6	2	3
Iron and steel	2	0	−7	−2
Internal combustion engines	1	2	−1	7
Semiconductors	1	3	−2	1
Telecommunications	1	−6	−3	3
Milling machines	−1	−1	−5	−3
Nuclear energy	−2	1	−3	0
Jet engines	−2	1	−3	−4
Light–wave communications	−3	8	8	10
Solar energy	−4	12	19	21

[1] Nationality of inventor.

SOURCE: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office, *OTAF Custom Report, Selected Technologies, 1969-1983.*

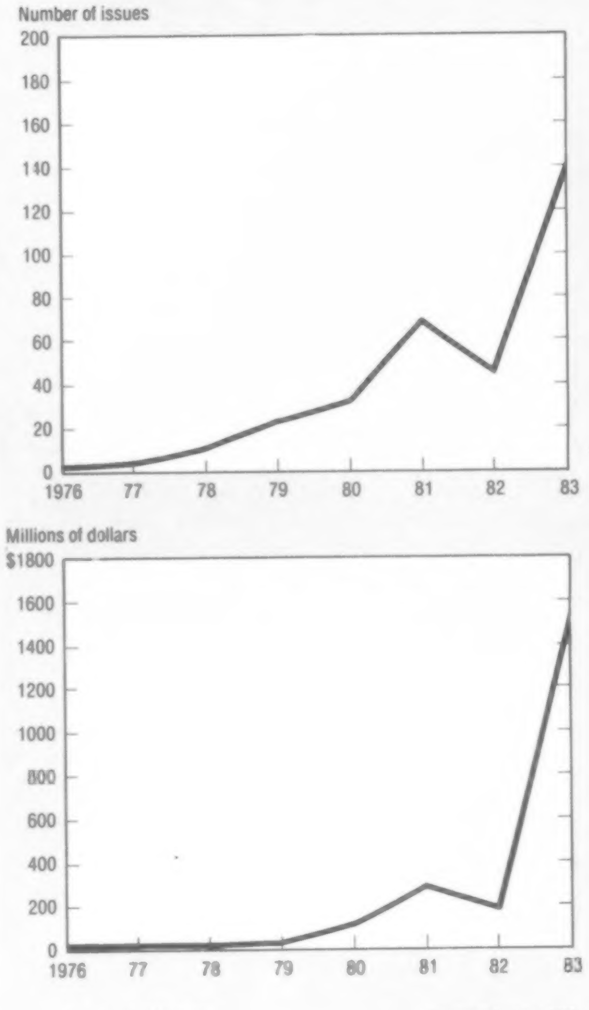
produce especially large numbers of new jobs and technological advances.[36] This is particularly true of the high-technology component of the small-business sector.[37] Largely for this reason, recent legislation requires Federal agencies with annual extramural R&D obligations over $100 million to establish a Small Business Innovation program and to allocate 1-1/4 percent of their grant and contract funding for the performance of research and development to small companies by fiscal year 1986.[38]

The strength of the high-technology small business sector can be gauged in part by looking at the financial resources available to it. These resources affect the amount of innovative activity these companies are able to conduct. For example, many small companies offer their stock for public sale at some stage in their development. This is an important source of funding that often makes considerable expansion of a company possible. Figure 4-8 shows the dramatic increase in the number and total dollar amount of initial stock offerings by these companies since 1976. This increase, which was especially pronounced from 1982 to 1983, has several reasons. They include the recovery from the recession of the mid-1970's, simplification of the Securities and Exchange Commission's requirements for the registration of small initial public offerings, reductions in the capital gains tax, relaxation of Department of Labor rules in 1979 regarding pension fund investments in venture capital partnerships, and changes in the general level of stock prices.

Earlier in their histories, small companies usually depend on private funding, and then on the venture capital industry. Venture capital companies provide early-stage development funding as well as later-stage expansion funding for companies that have grown beyond the stage of private funding but do not yet have access to public or credit-oriented institutional funding. Appendix table 4-11 shows the capital that these companies have had available and have paid out to small business.[39]

The net amount of new private capital committed to venture capital firms decreased steadily from 1970 to 1975, though it was always a positive amount.[40] From $10 million in 1975, the net new committed capital increased remarkably to $4.5 billion in 1983 and $4.2 billion in 1984. From 1980 to 1983, there was more than a 6-fold increase. The reasons for this increase are in many cases similar to the reasons for the increase in new public stock offerings. As a result, the total pool of capital under the management of venture capital companies rose from $2.6 billion in 1970 to $16.3 billion in 1984, in current dollars. Correspondingly, the funds disbursed to small companies annually from this pool have increased considerably since 1975. (See appendix table 4-11.)

Figure 4-8
Initial public offerings of stock in high-technology companies



See appendix table 4-10.

Science Indicators—1985

Most of the monies disbursed by venture capital companies are used to acquire equity positions in the small businesses they support. These funds can be classified by type of industry, as shown in appendix table 4-12. Thus, funding to high-technology manufacturing increased by a factor of 20 between 1975 and 1983 and by a factor of 4 between 1980 and 1983. The increase in nonmanufacturing industries was even greater, in percentage terms. Such industries include a certain number of service industries, such as computer services and communication services, that can also be considered technology-related.

Data are given for early- and later-stage funding of new ventures and for the total. Early-stage funding goes to companies at the stages of proof-of-concept, product development, or initial production or marketing. Expansion financing goes to companies that have established production and shipping histories, yet require additional external capital to finance further plant expansion, marketing, working capital, or product development. Following these definitions, figure 4-9 divides total equity funding into the two stages. Most of the support for high-technology manufacturing companies is later-stage, but great increases have occurred at both stages. Thus, from 1980 to 1983 early-stage funding increased by 160 percent and later-stage funding by 245 percent, for an overall increase of 208 percent.

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[36] A small company is usually defined as one with fewer than 500 employees. However, other definitions are also used in this chapter, according to the available data.

[37] The definition of high technology is variable. Ordinarily, the term is applied to manufacturing companies that fall within certain Standard Industrial Classes. A list of the classes regarded as high-technology in this discussion of small business is given in appendix table 4-13.

[38] For a discussion of the legislation and Federal agency activities under it, see Small Business Administration (1985), pp. 405-414.

[39] A recent study of the venture capital industry is reported in Joint Economic Committee (1984).

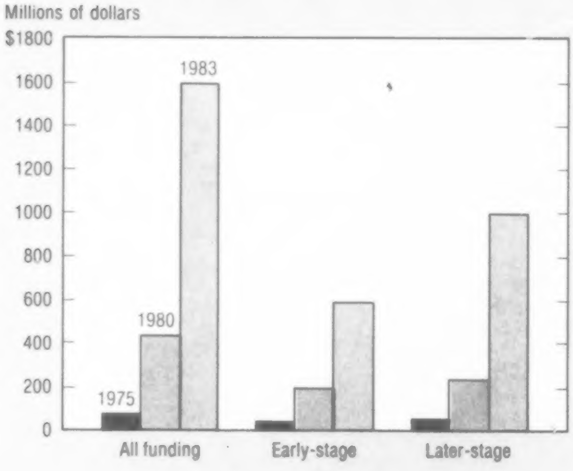
[40] These data apply to all small business, not only the high-technology component. They cover 200 leading U.S. private investors and, to a lesser extent, 400 less active investors. For recent years, 85-95 percent of all private-sector investment is included. See Venture Economics (1984).

The specific technology fields in which this funding occurs can be seen in appendix table 4-13. Investment has been highly concentrated in a few fields, such as office, computing, and accounting machines, and communication equipment and electronic components. A great deal of this funding is computer-related. Among nonmanufacturing fields, computer services has risen rapidly, to become 11 percent of all venture capital funding in 1983, or about $270 million.

Another listing, that does not use the Standard Industrial Classification, shows that in 1983, 39 percent of all investment was in computer hardware and systems and another 8 percent in software and related services.[41] Genetic engineering has had a declining share of total venture capital investment funds in recent years. However, in actual dollars it was at an all-time high of $66 million in 1983. Medical- and health-related investments have had the most rapidly increasing share of total venture investments, next to the computer-related technologies. In 1983, the medical technologies received at least $251 million.

Figure 4-9

Venture capital investments in small high-technology manufacturing companies



See appendix table 4-12.

Science Indicators—1985

The data discussed above concern the financial inputs into high-technology small business. Other data show that the net formation rates of high-technology establishments (of all sizes) are consistently at least twice the rates for non-high-technology establishments.[42] In the size range of 100 to 1,000 employees, the net number of new high-technology establishments between 1976 and 1980 was four times the number of new establishments that were not high-technology.

While the formation rates and the funding of high-technology small business can be followed in some detail, there is much less information available on the outcomes produced by these resources. However, recent limited studies have illuminated the contribution of this sector to employment and technological innovation. Thus, from 1976 to 1980 high-technology companies of all sizes increased their total employment by 19 percent, as compared with 12 percent in low-technology manufacturing and business services. As a result, in 1980 high-technology industries accounted for 22 percent of all manufacturing and business service employment. In this period, about 42 percent of the growth in manufacturing employment and 26 percent of the employment gains from formations of new manufacturing establishments were in high-technology industries.

Firms with fewer than 500 employees had only 24 percent of all employment in high-technology industries in 1980. However, these firms dominated in employment growth. High-technology small firms expanded their employment at an annual rate of 8.3 percent from 1976 to 1980, while all other high-technology firms expanded at a 3.5 percent rate. Further, the rate of employment growth in high-technology firms with fewer than 100 employees was 10.4 percent per year, far above the rate in the other size classes.[43]

The other major benefit attributed to small business, besides employment, is technological innovation. One dimension of innovation is the new products marketed by manufacturing companies. Recent data (see figure 4-10) indicate the rate of introduction of new products to the marketplace in a recent year, 1982, by companies of different sizes. The smallest company-size group clearly produced the greatest number of products per million dollars of R&D. As appendix table 4-14 shows, this is also true of the number of products per million dollars of net sales. Moreover, the number of products per R&D or sales dollar decreases uniformly as company size increases. This provides considerable evidence in support of the relative innovativeness of smaller companies, as measured by new products.[44]

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[41] Venture Economics (1984), p. 25. Dollar values are low estimates, since the data base does not cover all new ventures.

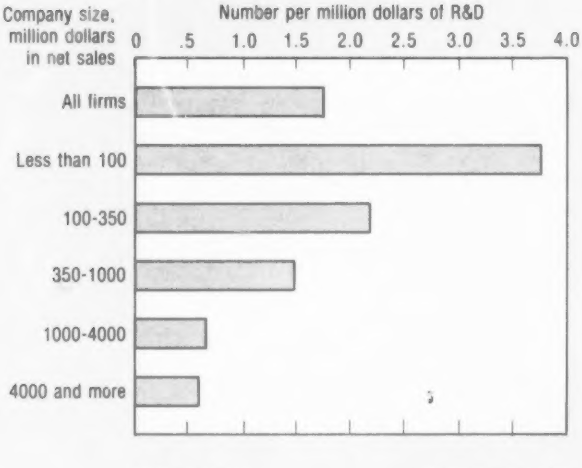
[42] Harris (1984), p. 8. The definition of high technology used here differs slightly from those used in the preceding discussions.

[43] Data also show that small high-technology companies had a higher employment growth rate than other small companies. See Harris (1984), Table 3.

[44] A recent study examined the economic returns to the innovating companies from a sample of innovations. These returns were compared with the returns to society as a whole. The evidence suggests that the ratio of social to private returns is considerably greater for small firms than for others. See Romeo and Rapoport (1984).

Figure 4-10

New products introduced in 1982, per million dollars of R&D



See appendix table 4-14. Science Indicators—1985

UNIVERSITY-INDUSTRY COOPERATION IN SCIENCE AND TECHNOLOGY

The industrial sector and the college and university sector are becoming increasingly dependent on each other in areas related to science and technology. Industry is dependent on the universities to educate the scientists, engineers, and managers who will perform its S/T-related activities. Universities also perform much of the basic research that it is not cost-effective for industry to undertake, but that industry will ultimately use in developing commercial products or processes.

Universities and colleges, in turn, benefit from financial support provided by industry in areas of mutual interest. In recent years, there have been increasingly frequent formal arrangements between universities and private companies. These take such forms as university-based centers and institutes supported by industry, jointly owned or operated laboratory facilities, research consortia, cooperative research programs under contract with industry, innovation centers, and industrial liaison programs. Both sectors benefit from the temporary, or permanent, exchange of personnel, and from the use of research results published in the open journal literature.[45]

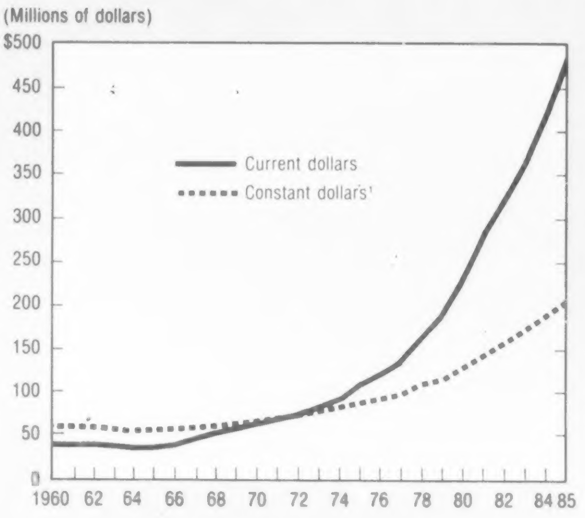
The Federal Government has sought to encourage joint university-industry arrangements without making large outlays. The Economic Recovery Tax Act of 1981 provides for a 25-percent tax credit for increases in company R&D expenses over and above base-year R&D expense levels. Companies may include up to 65 percent of contract research or basic research grants to colleges, universities, and certain other research organizations as part of their own R&D expenditures. In addition, the Act encourages the donation of research equipment to universities by allowing the deduction of part of the cost of such equipment as a charitable contribution.[46] Since the Act expires at the end of December 1985, the future of these provisons is uncertain.

The amount of direct support by industry to university R&D is shown in figure 4-11.[47] Even in constant-dollar terms, this support has increased every year since 1970. From 1981, the year of the Economic Recovery Tax Act, to 1984, constant-dollar industry support is estimated to have risen by 8.5 percent per year, on average. If gifts and loans of research equipment were included, the increase would probably be even greater. However, even in 1984 industry contributed only 5 percent of the total direct support for academic R&D.[48]

Scientific and technological activities in industry depend considerably on knowledge received from the university and college sector, whether or not the work was supported by industry. Particularly in basic research, academia produces freely published information that is picked up and

Figure 4-11

Industry expenditures for R&D in colleges and universities



[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

NOTE: Preliminary data are shown for 1983 and estimates for 1984 and 1985.

See appendix table 4-15. Science Indicators—1985

used in many different companies and industries. At the same time, technical information is transferred in the opposite direction, from industry to universities and colleges. This information transfer takes many different forms, and a measure of the total information transferred is probably not possible. The following discussion focuses on two sorts of indicators—personnel and journal literature—that reflect this information transfer.

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[45] On the general subject of university-industry relations in science and technology, see National Science Board (1982a), National Science Board (1982b), and Cornell University (1984).

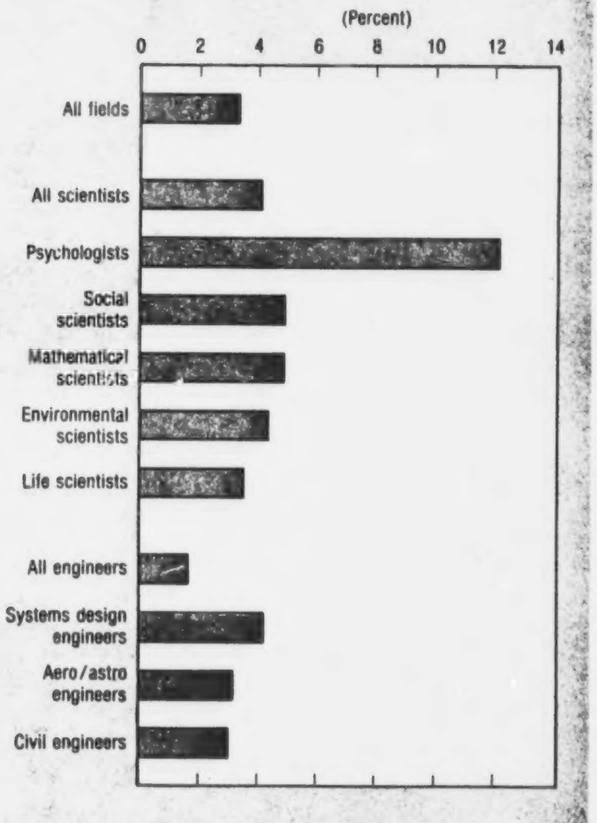
[46] See PL 97-34.

[47] The figure does not include indirect forms of support, such as unrestricted gifts to universities and colleges, grants from nonprofit foundations funded by industrial companies and gifts or loans of research equipment. See National Science Board (1982b), p. 27. For 1982-83, a sample of academic departments in electrical engineering, chemistry, and economics reported receiving 4 dollars in research equipment and gifts from industry for each 7 dollars received in the form of research grants and contracts. See National Science Foundation (1985a), p. 69.

[48] See National Science Foundation (1984b), p. 28.

Some industrially employed scientists and engineers with doctorates maintain their contacts with the academic sector by teaching part-time in an academic institution. The total number of such personnel is fairly small—no more than 3 percent of doctoral S/E's in industry. (See figure 4-12.) Still, they provide a valuable link between the sectors.[49]

Figure 4-12
Distribution by selected field of doctoral scientists and engineers in industry reporting teaching as a secondary work activity: 1983



See appendix table 4-16.

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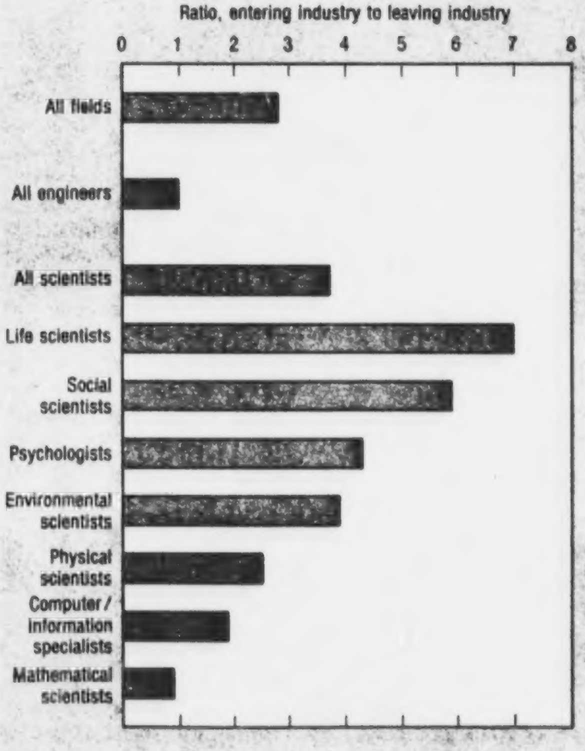
The number of scientists reporting such activity in 1983 is much greater than the number of engineers. It is also 55 percent greater than the number of doctoral scientists in industry who reported doing some teaching in 1979.[50] About 40 percent of teaching scientists in industry are psychologists, which is far out of proportion to the total number of doctoral psychologists in industry. (See appendix table 4-2.) Among engineers, only systems design engineers show a level of teaching activity comparable with that of scientists.

While some doctoral scientists and engineers work part-time in the university sector as teachers, others leave industry and take up full-time academic positions. There is also a flow in the other direction, from academia to industry. This is a very important means of transferring information and techniques between sectors. Figure 4-13 shows the ratio of doctoral S/E's entering industry to those leaving, for various fields, between 1981 and 1983. Appendix

Figure 4-13
Flow of doctoral scientists and engineers between industry and academia: 1981 to 1983



See appendix table 4-17.

Science Indicators—1985

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[49] The data shown on the figure also include in-house teaching by industry personnel. Numbers on figure 4-12 and appendix table 4-16 are extrapolated from a sample of industrially employed scientists and engineers.

[50] See appendix table 4-16 and National Science Board (1983), p. 294.

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table 4-17 shows the numbers of persons moving in either direction.[51]

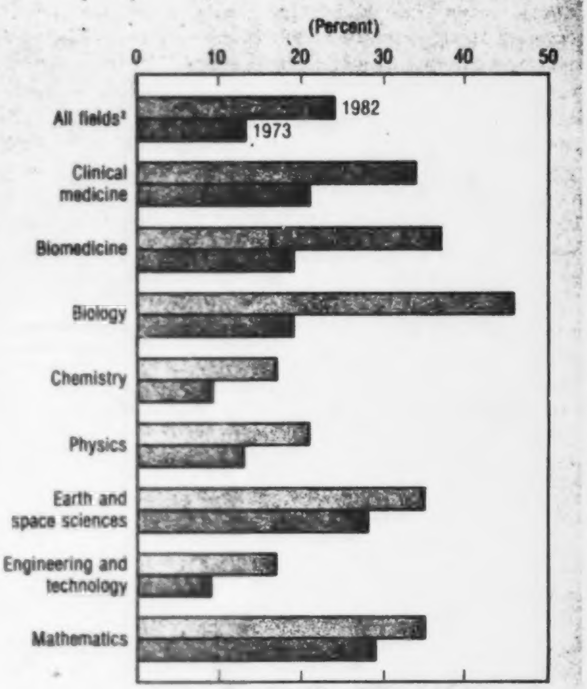
The overall tendency is for personnel to enter industry from academia. This is because of the number of scientists transferring; engineers transfer almost equally in either direction. Among scientists, only mathematical scientists tended to leave industry more often than to enter it over this two-year interval. Clearly, doctoral life scientists and social scientists were the ones who most frequently left academia for industry, rather than the reverse. In the preceding two-year interval, from 1979 to 1981, the ratio of all doctoral scientists and engineers entering industry to those leaving was even greater (4.5) mainly because fewer moved from industry to academia. This was especially true of engineers and environmental scientists.

Many more mathematical scientists entered industry from academia between 1979 and 1981, and substantially fewer left for academia. There were far fewer computer specialists moving in either direction between 1979 and 1981 (as compared with the 1981-83 interval), probably because considerably fewer computer specialists were employed in either sector in the earlier period.

A sample survey performed in 1984 found that 35 percent of electrical engineering faculty in reporting academic departments had prior industrial experience. In chemistry departments, 9 percent had industrial experience, and in economics departments, 6 percent.[52] Faculty in each of the three fields spent an average of about 2.7 days per month in outside "consulting", though there is no indication of how much of this was with private industry.[53]

The extent of information transfer between industry and academia is also reflected in the professional journal literature. For example, research papers are published having authors from both sectors. This may occur because investigators in the two sectors do a project together or because a former student takes a position in industry and writes a research paper along with his or her academic mentor. Figure 4-14 shows the extent to which industry authors of journal papers have shared authorship with someone in the university sector. The fraction of industry-authored papers that had academic co-authors nearly doubled from 1973 to 1982.[54] A very large increase occurred in biology, in which nearly half of the papers with an industry author are now co-authored between the two sectors, perhaps because of the rapid growth of biotechnology projects with both academic and industry participants. Large increases also occurred in biomedicine and clinical medicine, perhaps for the same reason.

Figure 4-14
Portion of all journal publications[1] written with industry participation that are co-authored with universities



[1] Includes the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-7.

[2] See appendix table 1-6 for a description of the subfields included in these fields.

See appendix table 4-18. Science Indicators—1985

OVERVIEW

The private-industry sector is the site of most of the R&D in the United States, with 73 percent of all R&D dollars being spent in industry. More broadly, industry is the major performer of the Nation's total S/T activities, with four-fifths of all employed engineers and half of all scientists. From these efforts come most of the new technologies that affect the economic and social welfare of the public.

The resources devoted to these industrial activities have been maintained, and have even increased, in spite of fluctuations in the economy. Since 1976, the employment of industrial scientists and engineers has increased much faster than overall industrial employment. Similarly, industrial R&D funding in constant dollars has been rising every year since 1975, with an increase in recent years of 6.0 percent per year. Private industry itself pays for two-thirds of industrial R&D. From 1984 to 1985, an increase in private funding of 7 percent is forecast, in constant dollars. Some of the increased private spending can be attributed to the Economic Recovery Tax Act of 1981. Federal support increased at a slower pace from 1975 to 1980, but it has accelerated since 1980. Defense-related work has been a major part of this increase.

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[51] For the sake of comparison, there was a total of 99,000 doctoral scientists and engineers employed in industry in 1981, and 187,000 employed in academia. See National Science Foundation (1982), pp. 4, 5.

[52] See National Science Foundation (1985a), p. 51.

[53] See National Science Foundation (1985a), p. 65.

[54] For intermediate years, see appendix table 4-18.

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Other indications of the health of industrial science and technology can be seen in the funding available for high-technology small business. This component of the private business sector is considered especially important as a source of technological innovations and new jobs. For this reason, Government policy has encouraged small business in several ways. The maximum capital gains tax has been lowered, most recently in 1981, thereby encouraging private investment. In addition, the Small Business Innovation Development Act of 1982 requires Federal agencies with large extramural R&D budgets to allocate a certain portion of those funds to small companies. Private venture capital has, in fact, flowed into high-technology small companies in record amounts, reaching a total of $16.3 billion in 1984. New public offerings of stock in high-technology industries have also increased substantially, particularly in 1983, when they reached $1.5 billion.

Small companies in high-technology industries have increased their employment much faster than large companies in such industries. From 1976 to 1980, the larger companies grew in employment by 3.5 percent per year, while small companies grew at an 8.0 percent rate. In addition, the success of small companies in producing innovations is suggested by the fact that a sample of such companies introduced twice as many new products to the market in 1982, per R&D dollar, as did all the companies studied.

For all U.S. industry, the production of new technology can be measured in part in terms of the number of newly patented inventions. There was a general decline in the filing of successful patents by American inventors, including those employed in industry, from 1969 to 1979. Since 1979, the trend has been less certain, but is generally upward. Hence, there is some evidence that R&D increases in industry since 1975 have led to a lagged increase in technical inventions.

In a few high-technology fields, the indicators taken together show exceptional levels of S/T activity. In genetic engineering, for example, patenting increased at the remarkable rate of 53 percent per year from 1978 to 1984. Venture capital financing of new companies in this field reached an all-time high in 1983, though in recent years this technology has been getting a declining share of all venture funding.

Computers and related technologies make up another area of high activity. Computer specialists are by far the most rapidly growing group of scientists or engineers in industry; their numbers grew by 18 percent per year from 1976 to 1983. Patenting in computer-related technologies has also been increasing significantly. In digital computer systems themselves, the growth rate in patent grants was 10 percent per year from 1978 to 1984, while total patent grants were declining by 3 percent per year. Computer-related companies are the largest and fastest growing group of small companies in terms of receiving venture capital financing. In 1983, computer hardware and systems accounted for 30 percent of funding, while software and services, which were growing especially rapidly, accounted for 13 percent.

Nonmanufacturing industries that perform R&D had high employment growth from 1973 to 1983, while employment was declining in high-technology manufacturing and other manufacturing industries. Computer and data processing services are a significant component of this rapidly growing nonmanufacturing sector.

Another aspect of the health of industrial science and technology is their connection with S/T activity in the academic sector. Academic research is recognized as providing a necessary base for more applied R&D in industry. In addition, technically trained personnel come to industry from the academic sector. For these reasons, Federal tax law encourages research contracts between industry and universities, as well as research equipment donations by industry.

There are several indicators of the degree of interaction and information exchange between these two sectors. Since 1981, the year of the Economic Recovery Tax Act, universities report that direct support by industry to academic R&D has increased by an estimated 8.5 percent per year, in constant dollars. This is greater than the rise in industry's funding of research within its own sector, but is below the rate of increase in university R&D support by industry over the preceding three years. One measure of information transfer between sectors is the number of professional personnel who leave a job in one sector and take up employment in another. This transfer, of course, also reflects changes in the job market. The predominant movement has been from academia to industry. Between 1981 and 1983, about 4,800 doctoral scientists and engineers (3 percent of the total employed in this sector) left academia for industry, while 1,700 (2 percent of such employees in industry) moved in the other direction. In the preceding two-year period, the proportion moving into industry was even greater.

Another measure of the interaction between the university and industry sectors is the number of research papers jointly published by authors in the two sectors. From 1973 to 1982, the fraction of industry-authored papers with a university co-author nearly doubled, going from 13 to 24 percent. In biology, nearly half the industry-authored papers now have academic co-authors. Large increases in co-authorship have occurred in biomedicine and clinical medicine. This may be another reflection of the great expansion in recent years of genetic engineering and related fields of research.

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Chapter 5

Academic Science and Engineering

Academic Science and Engineering

HIGHLIGHTS

- *Increased Federal support for academic R&D.* After growing at an average annual constant-dollar rate of 2.8 percent between 1980 and 1984, total expenditures for academic research and development (R&D) grew by 7 percent between 1984 and 1985 to reach a total of $4.1 billion in 1972 constant dollars. Federal expenditures for academic R&D accounted for two-thirds of the growth observed between 1984 and 1985. (See pp. 107-108.)

- *Increased academic basic research.* As a result of new funding emphases, academic expenditures for basic research grew at an average annual rate of 4.1 percent (in constant 1972 dollars) between 1980 and 1985. In contrast, academic applied R&D expenditures grew at an average annual rate of 3.1 percent during the same period. Increased Federal support accounted for much of the growth in academic basic research. Between 1980 and 1985, Federal support for academic basic research grew at an average annual rate of 3.6 percent, accounting for two-thirds of the growth observed during that time. By 1985, basic research represented 68 percent of total academic R&D expenditures, up from a level of 66 percent in 1980. (See p. 108.)

- *More freshmen choosing engineering and computer science majors.* Approximately one-third of the freshmen registered in U.S. colleges and universities in 1983 indicated that their probable field of study would be science or engineering, a level comparable to that recorded in 1974. By 1983, engineering had surpassed the social sciences and the biological sciences as the most popular selection of probable S/E majors. In addition, 5 percent of the 1983 freshmen planned to major in the computer sciences, up from 1 percent in 1974. The proportion of probable S/E majors planning a career in medicine or a related health profession declined from 23 percent in 1974 to 11 percent in 1983. (See pp. 98-99.)

- *Foreign graduate student enrollments up in science and engineering, but down at top schools.* Between 1980 and 1983, total full-time enrollment in graduate S/E programs grew by 6 percent. Foreign student enrollment accounted for 85 percent of the net growth. In 1983, while foreign students constituted 25 percent of all full-time S/E graduate students, they made up 42 percent of enrollments in engineering, 40 percent in mathematics, 38 percent in the computer sciences, 29 percent in the physical sciences, and only 4 percent in psychology. Enrollments of foreign students in graduate departments rated the top 25 percent in terms of quality declined from 40 percent in 1977 to 35 percent in 1983. (See pp.100-102.)

- *Federal support for graduate research training in science and engineering continues to decline.* Between 1980 (the recent peak year of Federal support) and 1983, the number of full-time S/E graduate students receiving Federal support declined by about 10 percent, or about 6,000 students. Substantial reductions in the number of full-time S/E graduate students with Federal fellowship support (whose numbers declined by 28 percent between 1980 and 1983) accounted for most of the decline. Increased research training support from non-Federal sources has offset the decline in Federal training support. By 1983, non-Federal funding represented the primary source of research training support for full-time S/E graduate students in doctorate-granting institutions, accounting for 53 percent of the total number of students with fellowships, traineeships, or research assistantships. (See pp. 101-103.)

- *Faculty increases in engineering and computer science, but drops in physical science.* Between 1981 and 1983, the number of doctoral scientists and engineers employed in 4-year colleges and universities grew by 5 percent. The greatest growth occurred among doctoral-level computer specialists whose numbers expanded by 30 percent, followed by doctoral-level engineers (up 12 percent). The number of doctoral-level physical science faculty declined by 2 percent between 1981 and 1983. (See p. 104.)

- *Biosciences lead academic research literature growth.* Academic institutions provide about two-thirds of the research literature in the most influential science and technology journals, a ratio that has increased slightly in the past 10 years. Between 1973 and 1982, the number of academically authored articles grew by 9 percent, with the greatest increase occurring in biomedicine (24 percent), clinical medicine (21 percent), and biology (11 percent). (See pp. 105-106.)

- *Expenditures on research equipment up.* In 1983, an average of about $7,200 was spent in the academic sector for the purchase of research equipment for each full-time equivalent research scientist or engineer, up from $6,900 in 1982. According to a 1982 survey, the median age of academic scientific instruments in the eight fields surveyed was 6 years. About 46 percent of the department chairpersons in those fields viewed the research instruments as "inadequate" for permitting investigators in their departments to pursue their major research interests. (See pp. 113-114.)

- *Broader use of large-scale academic research facilities urged.* Federal policies for the improvement of academic research facilities in the 1980's place substantial empha-

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sis on broadening the utilization of existing facilities. In the area of supercomputers, for example, Federal efforts are underway to increase access to advanced computer resources through electronic networks linked to a limited number of university-based supercomputers. (See p. 115.)

The demand for academic science and engineering continues to grow in the United States. This growth is evident in the higher rates of investment from both public and private sources for basic research performed in the academic sector,[1] as well as in S/E enrollment growth and good employment opportunities for S/E graduates in many fields.[2]

The success of academic science and engineering in fulfilling its dual research and teaching mission depends on an institutional environment which can support excellent scientific and technological activities. Numerous resources are needed, including dedicated and talented faculty; bright, motivated students; adequate levels of funding; up-to-date technical instruments; and properly maintained facilities.

The indicators presented in this chapter analyze recent trends in academic science and engineering. The first section traces some changing patterns in the organization of S/E on U.S. campuses. Special attention is given to support for graduate S/E training, to new patterns of funding for academic R&D, and to emerging relationships between university and industrial sectors.

The second part of the chapter examines recent changes in S/E faculty activities, including trends in R&D activities, especially renewed emphasis on basic research in many S/E fields. The role of faculty consulting is also described as it relates to the university-industry interface.

The chapter concludes with a review of the adequacy of the status of resources available to academic scientists and engineers. This section reports findings from a recent national inventory of academic research instrumentation and reviews recent Federal policies relevant to the improvement of academic research facilities.

THE ACADEMIC SCIENCE AND ENGINEERING SYSTEM

Academic administrators face the task of dividing limited fiscal and human resources among the diverse constituents of their institutions. How, for example, will they meet the growing demand for faculty members in one department while assuring the continuation of appropriate staffing levels in other, perhaps less popular, departments? Should the institution hire a patent administrator to capitalize on emerging patenting and licensing opportunities? What new funding arrangements can be made to respond to student demands for increased financial assistance? This section identifies some of the changes already underway in the organization of science and engineering on university campuses in response to some of these challenges and opportunities.

Institutions for Science and Engineering Education

Postsecondary education in S/E occurs in a variety of settings. In 1982, 1,457 4-year institutions, representing just over 70 percent of all 4-year postsecondary institutions in the United States, offered a baccalaureate (or higher) degree in at least one S/E field. (See appendix table 5-1.) The remaining 4-year colleges not offering degrees in S/E are primarily specialized institutions characterized by a programmatic emphasis in one area, such as business colleges.[3]

The number of institutions offering S/E degrees continues to grow, although in recent years there has been a considerable decline in growth. (See figure 5-1.) Between 1960 and 1975, the number of institutions granting S/E degrees grew overall at an average annual rate of 1.9 percent; since that time, growth in the number of S/E institutions slowed to an average annual rate of 0.3 percent. The number of S/E institutions in which the highest degree offered is a doctorate has continued to grow, as has the number whose highest offering is the S/E master's degree.

Average annual percent change

Highest degree	*1960-75*	*1975-82*
Baccalaureate	0.6	-0.2
Master's	4.3	1.0
Doctorate	4.3	1.4

Thus, since 1960, the shift in institutional growth has been clearly in the direction of advanced-level preparation in S/E.

While more institutions offer degrees in science and engineering than ever before, the number of degrees awarded has outstripped even that growth. (See figure 5-1.) For example, the number of institutions offering S/E doctoral degrees grew at an average annual rate of 3.4 percent between 1960 and 1975. The average yearly growth in the number of S/E doctorates granted in that period was 7.5 percent. Thus, on average, institutions not only increased in number but also increased in size between 1960 and 1975. Since 1975, the number of institutions offering S/E degrees has remained essentially level, changing only about 0.3 percent per year. Total S/E degree production followed a similar pattern at a rate of 0.3 percent per year. (See appendix tables 5-1 and 5-2.) The institutional expansion observed

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[1] For a description of some of the reasons behind increased public and private investment in academic research and development see Keyworth (1984); Young (1984); Bowen (1984); and Langenberg (1984).

[2] See also the chapter in this report on U.S. scientific and engineering personnel for a discussion of S/E employment trends.

[3] See National Center for Education Statistics (1984).

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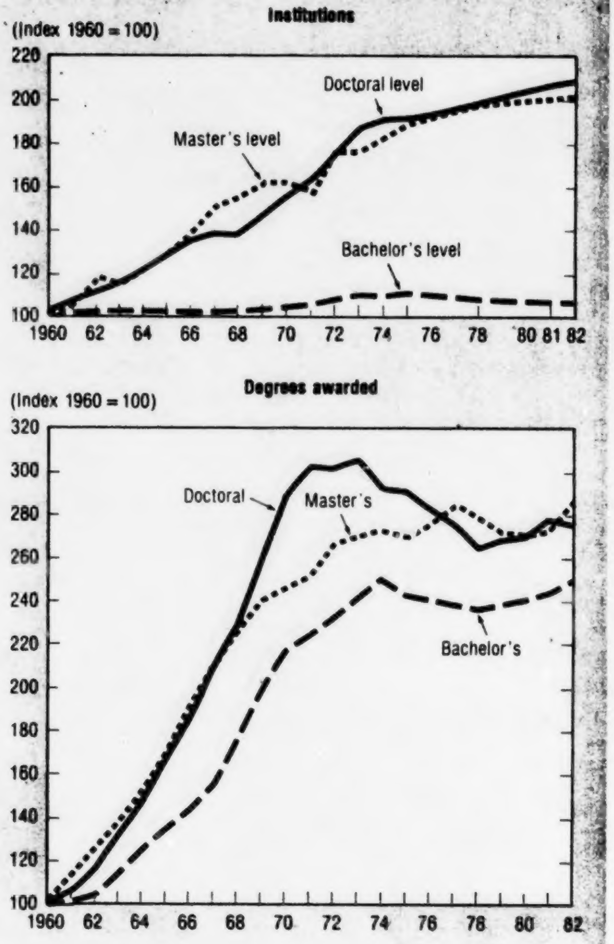
Figure 5-1

Relative growth in the number of institutions offering S/E degrees and the number of S/E degrees awarded



See appendix table 5-1 and 5-2. Science Indicators—1985

in the 1960's and early 1970's has apparently given way to a rather steady-state condition in S/E education.[4]

Program quality. Institutions differ with respect to the quality of the environment in which S/E training occurs. A recent analysis of programs in 30 disciplines revealed that the top 25 percent of the S/E programs were responsible for producing just over 40 percent of the Ph.D. recipients in 1983.[5] (See appendix table 5-4.) This proportion varied across the five broad S/E fields surveyed, as shown below:

Fields surveyed	*Percent of Ph.D. recipients from top 25 percent of rated programs*
Engineering	51
Physical/environmental sciences	50
Mathematics/computer sciences	48
Biological sciences	35
Social sciences[6]	32

Changes have occurred since 1973 in the rate at which the top-rated programs are contributing to the production of S/E doctorate recipients. Although top-rated programs were graduating fewer Ph.D.'s each year than they were in 1973, the decline in annual Ph.D. production was generally not as great as that observed for lesser-rated or non-rated programs. (See figure 5-2.) Only in the social sciences has significant growth occurred in the number of Ph.D. recipients trained in lesser-rated or non-rated programs, compared to the number produced in 1973. This trend has been accompanied by a yearly decline in the number of Ph.D. recipients graduating from institutions with top-rated social science programs.

As the number of Ph.D.'s produced by these S/E programs has changed, the distribution of new Ph.D. recipients across program quality has also changed. By 1983, 51 percent of the Ph.D.'s in engineering were trained in one of the top 25 percent of the rated programs, up from a level of 45 percent in 1973. Similar changes are evident in the physical and environmental sciences (from 45 percent of the total in 1973 to 50 percent in 1983), in the mathematical and computer sciences (from 46 percent to 48 percent), and in the biological sciences (from 32 percent to 35 percent). Only in the social sciences did the proportion of Ph.D. recipients trained in top-rated programs decline, from 40 percent of the total in 1973 to 32 percent in 1983.

In summary, more institutions offer degrees in science and engineering than ever before. In terms of program quality, top-rated research doctoral programs are graduating more Ph.D.'s than they were 10 years ago, while lesser-rated or non-rated departments are graduating fewer Ph.D.'s. An exception to this trend has occurred in the social sciences.

Engineering education. An important aspect of the changes underway in the organization of academic S/E education is the status of engineering education. In the past few years much attention has been directed at whether the supply of faculty members is adequate to meet the demands of growing student enrollments.[7] Given continued national inter-

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[4] The response of the higher education community to slower growth in the 1970's has been the subject of a number of studies, including Stadtman (1979); Carnegie Council on Policy Studies in Higher Education (1980); Bowen (1982), and Phillips and Shen (1982).

[5] For a listing of the S/E fields included in this survey, see appendix table 5-5. S/E doctoral programs were rated along 16 dimensions. The findings reported in this section are based on measure 8: "Mean rating of the scholarly quality of program faculty." See Jones, Lindzey and Coggeshall (1982).

[6] Includes psychology.

[7] Faculty shortages in engineering education have been the subject of a number of reports. See, for example, National Society for Professional Engineers (1982); Botkin et al. (1982); Geils (1982); Business-Higher Education Forum (1982); Mann (1983); and Upthegrove (1984).

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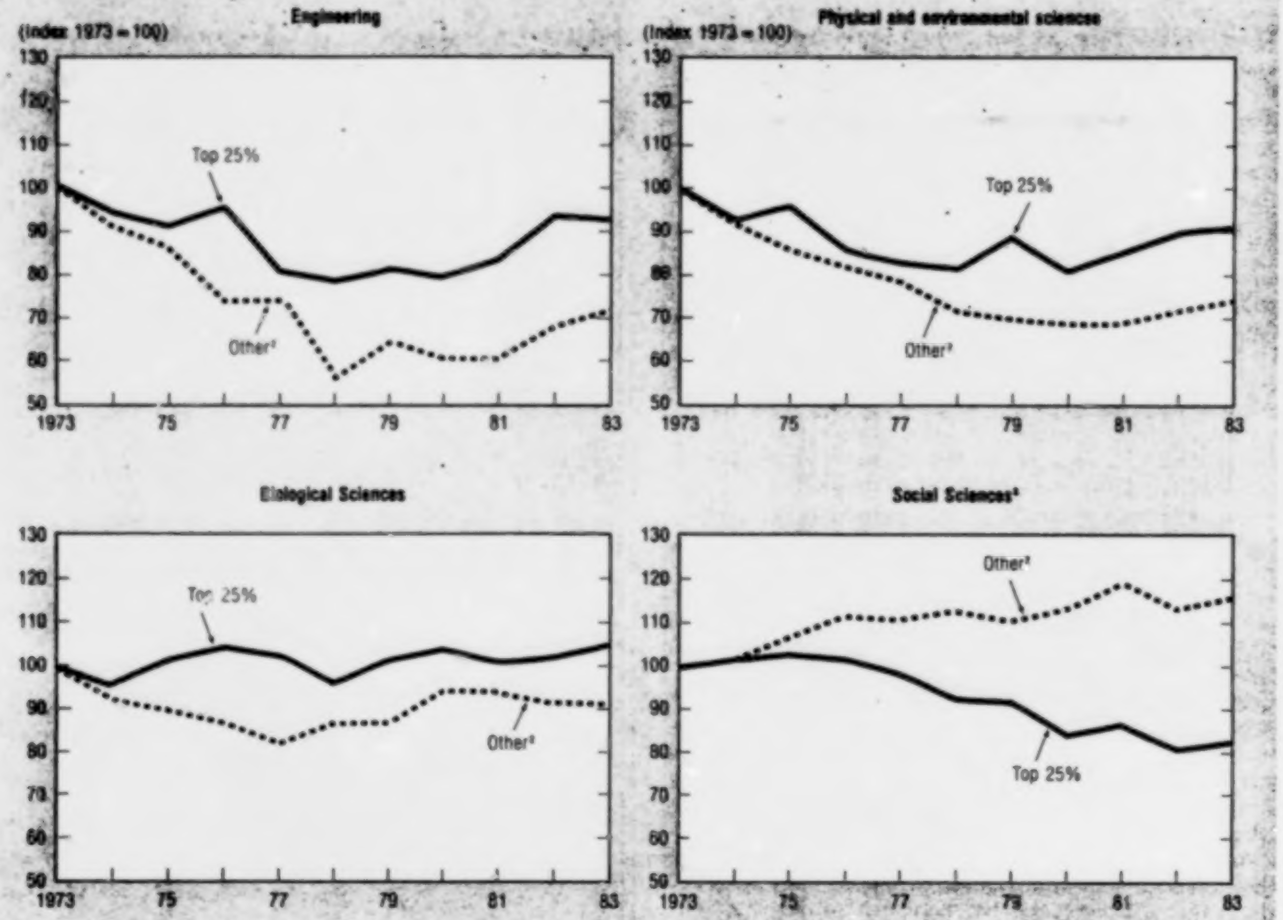
Figure 5-2

Relative change in the number of doctoral recipients by program quality rating[1] and selected S/E fields



[1] As ranked by the reputational survey of the Conference Board of Associated Research Councils (1981).

[2] "Other" includes doctoral recipients in departments not rated by the reputational survey.

[3] "Social sciences" includes psychology.

See appendix tables 5-4 and 5-5.

Science Indicators—1985

est in the production of researchers who can advance America's technological lead, concern over engineering education will undoubtedly persist.

In fall 1983, nearly a half million individuals were enrolled on a full-time (FT) basis in engineering programs at 292 schools of engineering, up from a level of about 300,000 in fall 1976. (See appendix table 5-6.) Four fields accounted for over 60 percent of total 1983 FT engineering enrollments[8] with the greatest enrollment growth occurring in electrical engineering (up 83 percent between 1976 and 1983), followed by mechanical engineering (up 77 percent), and chemical engineering (up 49 percent). Only in the field of civil engineering was there essentially no change in the total number of FT students. In aeronautical and astronautical engineering, FT enrollments grew by about 140 percent between 1976 and 1983. By 1983, enrollments in those fields accounted for 3 percent of total FT engineering enrollments, up from 2 percent in 1976.[9]

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[8] In 1983, four fields accounted for over 60 percent of FT engineering enrollments at the undergraduate and graduate levels combined: electrical (26 percent of total FT enrollments), mechanical (17 percent), civil (10 percent), and chemical (8 percent) engineering. These same four fields also accounted for the same percentages in 1976. See Alden (1977), p. 59 and Sheridan (1984), p. 47.

[9] Another major subfield in engineering is computer science and computer engineering, which accounted for about 6 percent of total FT enrollments in 1983. However, data are not available in a disaggregated form for 1976 to permit a trend analysis.

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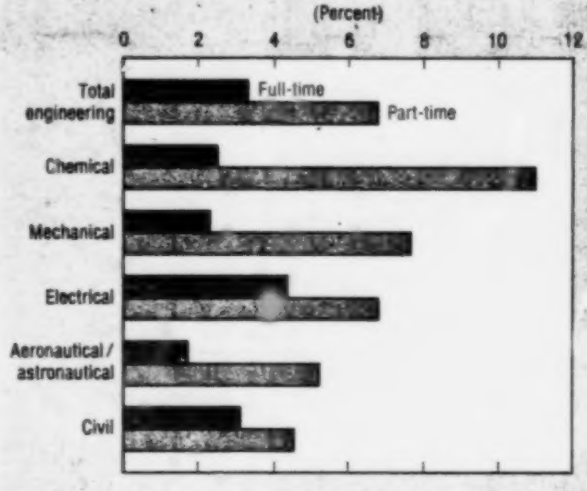
Faculty employment trends have not kept pace with enrollment growth in engineering. Between 1976 and 1983, academic engineering employment grew by 32 percent compared to the 57 percent overall growth in student enrollments. (See appendix tables 5-6 and 5-7.) A survey of engineering deans revealed that approximately 9 percent of all authorized FT engineering faculty positions were unfilled in fall 1983.[10] Electrical engineering reported a vacancy level of 10 percent, followed by mechanical engineering (8 percent), aeronautical/astronautical (8 percent), chemical (7 percent), and civil (5 percent). Higher vacancy levels were observed in certain smaller emerging areas, such as computer science and computer engineering (16 percent).[11] Differences were also reported in vacancy levels by institutional control. Public institutions reported that 10 percent of their authorized FT positions were unfilled in 1983, compared to a level of 5 percent for private institutions.[12] Further, vacancies in private institutions appear to have declined between 1982 and 1983, in contrast to the continued growth in vacancies in public institutions.[13] The greater flexibility private institutions have in adjusting faculty salaries to attract FT engineering faculty may be contributing to the differences in these employment trends.[14]

Figure 5-3

Relative average annual change in full-time and part-time engineering staff in U.S. colleges and universities, by selected subfield: 1976-83



See appendix table 5-7.

Science Indicators—1985

One approach to handling enrollment growth used by engineering deans has been to hire part-time (PT) engineering staff. As figure 5-3 indicates, the hiring of PT engineering staff has exceeded FT staff hiring in every major subfield of engineering, with the most pronounced differences occurring in those areas having the highest enrollment growth.

Despite these efforts, student-to-staff ratios continue to grow. As Table 5-1 suggests, the ratio of FT students to academic staff (both FT and PT) increased in almost every major subfield of engineering between 1977 and 1982. Only in the field of civil engineering, where enrollments remained essentially constant between 1977 and 1982, has the student-to-staff ratio declined. Among the engineering specialties, chemical engineering has had one of the highest student-to-staff ratios (22.5 students per staff member in 1982), followed by mechanical (20.8 students) and electrical (19.1 students). While there is no known "opitmal" ratio, concern has been expressed by a number of observers about the inability of engineering school deans to meet increased student enrollment through expansion of faculty numbers.[15]

Table 5-1. Ratio of full-time engineering students to FTE[1] academic staff in engineering, by selected subfield: 1977 and 1982[2]

Field	Fall 1977	Fall 1982
	(Number of students per staff)	
Total engineering	16.4	19.5
Aeronautical	9.6	17.5
Chemical	18.2	22.5
Civil	14.6	12.3
Electrical	16.3	19.1
Mechanical	15.5	20.8
Other	18.4	22.4

[1] FTE = full time equivalent.

[2] Based on fall enrollments of the year shown, and staff estimates for the following January.

SOURCES: Student enrollments from the annual survey of the American Association of Engineering Societies; staff counts from the National Science Foundation annual survey of academic S/E's.

Science Indicators—1985

In summary, certain important changes have come about in engineering education in the last few years. While students at both the graduate and the undergraduate levels are enrolled for the most part in four major engineering subfields, engineering enrollments have grown as a whole by almost 60 percent between 1976 and 1983. The inability of engineering deans to recruit and/or retain FT faculty has resulted in the greater use of PT faculty in engineering schools. Nonetheless, student-to-staff ratios remain high in every major engineering subfield.

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[10] See Doigan (1984), table 2, p. 51.

[11] Ibid. Faculty shortages in areas such as these were the subject of a recent conference. See McPherson (in press).

[12] Ibid.

[13] Between 1982 and 1983, engineering vacancies in private institutions declined from 7 to 5 percent, while those in public institutions rose from 8 to 10 percent. See Doigan (1984).

[14] In 1983, engineering faculty salaries at all ranks averaged $30,559 in public institutions and $35,569 in private institutions. Faculty salaries at public institutions average $27,395 across all fields, and average $26,080 at private institutions. See College and University Personnel Association (1984a and 1984b).

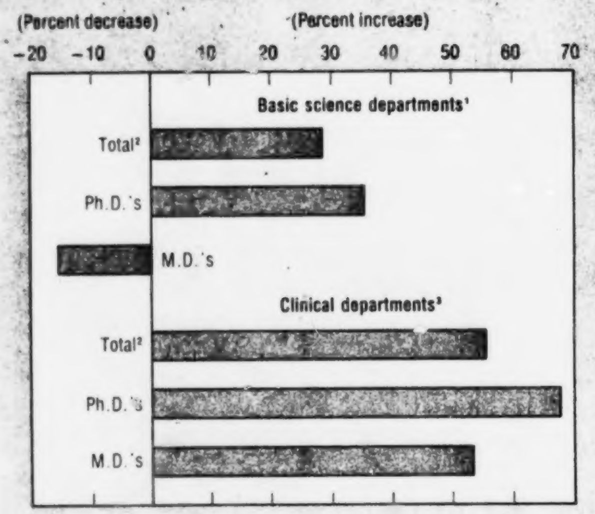
[15] See, for example, Business-Higher Education Forum (1982) for a discussion of the relationship of student enrollments and faculty hiring rates relative to the quality of the educational experience.

Education for biomedical research. American society has come to expect gains to be made in the state of its health and the quality of its health care. In response to those expectations, medical schools have evolved into large, complex academic medical centers that pursue their objectives through education, research, and patient care.[16] Medical schools have thus become a focal point for the blending of basic biomedical and behavioral research with the care of patients, as well as the education of physicians and medical scientists.

The number of accredited medical schools in the United States has grown from 86 in 1960 to 127 in 1983.[17] During the same period the number of full-time medical school faculty rose from 11,200 to 55,000, an increase from an average of 130 faculty members per medical institution in 1960 to 440 in 1983. Growth has occurred primarily in clinical departments,[18] which reported a total of 42,000 FT faculty members in 1983. In contrast, basic science departments reported a total of 13,500 FT faculty members.[19]

Medical schools play an important role in the scientific education of both medical researchers and physician practitioners through the introduction of biomedical concepts into the undergraduate medical curriculum,[20] through programs of research training for postdoctoral physicians,[21] and through programs of graduate education in the biomedical sciences for nonphysicians.[22] The medical school thus serves as an important locus for scientific training in the biomedical sciences.

Figure 5-4
Percent change in full-time medical school faculty by degree type and department: 1972-82



[1] Basic science departments include such fields as anatomy, biochemistry, microbiology, pathology, and pharmacology.

[2] Total includes M.D.'s plus Ph.D.'s only. These represented approximately 91 percent of all full-time faculty in basic science departments and 89 percent of all full-time clinical department faculty in 1982.

[3] Clinical departments include anesthesiology, dermatology, family medicine, internal medicine, and psychiatry.

See appendix table 5-8.

Science Indicators—1985

A major change in the medical school environment over the past decade is the rise in the number of Ph.D. scientists on medical school faculties. As figure 5-4 suggests, Ph.D. faculty in clinical departments increased by about 68 percent between 1972 and 1982, while M.D. faculty grew by 54 percent. Furthermore, Ph.D. faculty in basic science departments grew by about 35 percent, while the number of M.D. faculty in those departments declined.

One outcome of the growth in the number of Ph.D. faculty has been the emergence of the Ph.D. scientist as the primary performer of biomedical research in U.S. schools of medicine. In figure 5-5, almost 60 percent of medical school faculty serving as principal investigators on research grants awarded by the National Institutes of Health (NIH) or the Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA) in 1982 were nonphysician investigators. The marked decline in physician interest in research careers partially accounts for the relative gains of non-M.D. investigators in schools of medicine,[23] and has led a number of observers to speculate that clinical research may be hampered as a result of these trends.[24]

In summary, medical schools have grown in size and number over the past quarter century. Concurrently, more Ph.D. scientists have become members of medical school faculties. One result has been the emergence of the Ph.D. investigator in medical research.

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[16] See, for example, Association of American Medical Colleges (1983) for a brief review of the issues related to the evolution of medical education since World War II.

[17] Figures for 1983 include two U.S. schools offering the first two years of medical curriculum only. See Crowley, Etzel, and Petersen (1983).

[18] Clinical departments include internal medicine, psychiatry, pediatrics and surgery.

[19] Basic science departments in schools of medicine include such fields as anatomy, biochemistry, microbiology, pathology, pharmacology, and physiology.

[20] During the last quarter century, the undergraduate medical curriculum has been put under tremendous pressure by the rapid expansion of biomedical knowledge. Observers generally agree that more must be done to anticipate the scientific information needs of future medical practitioners. See Kemph, Claybrook, and Sodeman (1984); Wyngaarden (1984); Krevans (1984); and Bishop (1984).

[21] Since the mid-1960s, postgraduate medical education has increasingly been associated with schools of medicine. See Association of American Medical Colleges (1983). In 1983, 37 percent of all postdoctorals enrolled in research training in medical schools held a medical or other health professional degree, up from a level of 26 percent in 1982. See National Science Foundation (1984), p. 285 and unpublished tabulations.

[22] Medical schools train a significant proportion of biomedical scientists. In 1982, 40 percent of the graduate students engaged in the study of the biological sciences were enrolled in basic science departments in medical schools, up from a level of 37 percent in 1975. See Association of American Medical Colleges (1983) and National Science Foundation (1984).

[23] The decline of clinical investigators has been the subject of numerous reports. Chief among these are Thier (1979); Institute of Medicine (1983a); and Wyngaarden (1984).

[24] See, for example, Fuchs (1982) and Zusman (1983).

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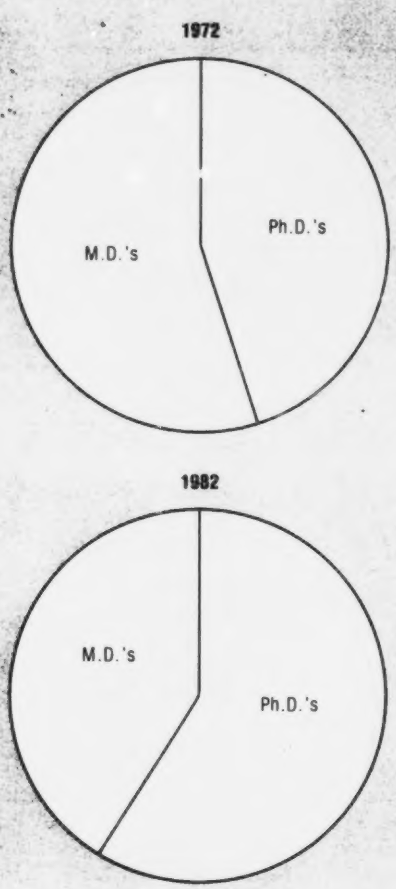
Figure 5-5
Relative proportion of Ph.D. and M.D. medical faculty identified as principal investigators on NIH[1] research grants: 1972 and 1982



[1] "NIH" includes National Institutes of Health and Alcohol, Drug Abuse, and Mental Health Administration.

SOURCE: Herman, S. S. and A. M. Singer, "Basic Scientists in Clinical Departments," Institute of Medicine, Washington, D.C., 1984.

Science Indicators—1985

STUDENT ENROLLMENT AND SUPPORT

The vitality of the S/T enterprise depends on a continuing flow of new talent. The precollege science and mathematics experience plays a significant role in the preparation of students for careers in science and engineering.[25] It is at the college science level, however, that the training of the nation's future scientists and engineers formally begins. This section explores changes that have taken place in the characteristics of entering undergraduates who planned to major in science or engineering. It also describes the trends in graduate S/E enrollment and traces emerging directions in the financial resources available to S/E students at the graduate level.

Freshmen Characteristics

In fall 1983, just over one million students registered for the first time as freshmen in U.S. 4-year colleges and universities,[26] representing an increase of about 7 percent over the level observed in fall 1974. Student interest in science or engineering as a major remained stable during that time—at about one-third of total freshmen in 1974 and in 1983.[27] However, significant changes have occurred in student preference for S/E majors, as shown in table 5-2. Consistent with the widespread perception that undergraduate

Table 5-2. Probable major field of first-time, full-time freshmen in the 4-year colleges and universities: Fall 1974 and Fall 1983

Probable Major field	Fall 1974	Fall 1983
	(Percent)	
Total Freshmen	100.0	100.0
Total S/E	33.4	32.0
Physical sciences	2.6	1.8
Mathematics	2.0	1.2
Computer science	0.8	4.9
Environmental sciences	0.8	0.4
Engineering	7.7	11.5
Biological sciences	8.3	4.7
Social sciences	11.3	7.6
Total other fields	61.6	61.9
Arts & humanities	13.7	9.7
Business	14.0	22.2
Education	11.6	6.5
Other	22.4	23.6
Undecided	5.0	6.1

SOURCE: Higher Education Research Institute, Cooperative Institutional Research Program, unpublished tabulations, October 1984.

Science Indicators—1985

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[25] The performance of the elementary and secondary school systems in science and mathematics education has been the subject of a number of studies in recent years, including: National Science Foundation (1980 and 1983); Shymansky and Aldridge (1982); National Science Board (1982 and 1983); National Commission on Excellence in Education (1983); and Johnston and Aldridge (1984). Also, see the chapter in this report on precollege science and mathematics education.

[26] Data throughout this section refer to first-time, full-time freshmen only. They are drawn from special tabulations provided by the Higher Education Research Institute (HERI)at UCLA, October, 1984. "First-time, full-time freshmen" excludes individuals who have transferred from 2-year colleges to 4-year institutions as full-time students, but includes any students who may have registered for college level courses in the intervening summer between high school graduation and their enrollment that fall as full-time freshmen at 4-year colleges [illegible] universities.

[27] S/E baccalaureate degrees have represented about 30 percent of total-bachelor's degrees since the 1950's. See National Science Foundation (1982).

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education has become increasingly "vocational" in nature,[28] entering freshmen appear to be selecting fields of professional study—such as business, engineering, and computer sciences—with greater frequency.[29] As entering freshmen have gravitated toward these professional fields, a shift has also occurred in the highest degree to which students aspire. (See table 5-3.) In 1983, 37 percent of the probable S/E majors intended to terminate their formal education after earning a master's degree, up from a level of 30 percent in 1974. (See appendix table 5-9.) An attendant decline occurred in the proportion intending to earn professional doctoral degrees other than the Ph.D. or Ed.D. —such as M.D. or J.D. degrees.

The type of professional careers these freshmen intend to pursue has also changed. In 1974, 12 percent of the entering freshmen planned to pursue a career in business, compared to 20 percent in 1983. A decline occurred in student interest in health professional careers,[30] down from 17 percent of all freshmen in 1974 to 12 percent in 1983, and from 23 percent of all freshmen intending to major in science or engineering to 11 percent in 1983.

An issue of intense interest to the education community is the question of changes in the quality of students enrolled in the study of science and engineering, although adequate measures of "quality" are often elusive. Two recent studies of the opinions of senior academic officials found no perceived change in the quality of students in the sciences or humanities.[31] Another measure of student quality is the high school grade point average (GPA). In 1983, 28 percent of the freshmen reported their average high school grade to have been an "A," a level essentially unchanged from that reported in 1974.[32] In 1983, "A" students preferred to major in engineering (17 percent) and business (16 percent), followed by arts and humanities (9 percent), social sciences (7 percent), and biological sciences (7 percent). (See figure 5-6.)

Another measure reflecting the "quality" of entering freshmen is the level of their precollege preparation in science and mathematics. As appendix table 5-11 reveals, freshmen intending to major in science or engineering generally had more preparation in mathematics than those intending to major in other fields. There are even greater differences when previous experience with the physical sciences is considered. In 1983, slightly more than one-third of the intended S/E majors reported having had at least 3 years

Table 5-3. Relative proportion of first-time, full-time freshmen hoping to attain master's or doctor's S/E degree, by probable major field: 1974 and 1983

Probable major field	Master's 1974	Master's 1983	Doctor's[1] 1974	Doctor's[1] 1983
	(Percent)			
All S/E fields	30	37	19	18
Physical sciences	20	26	35	33
Environmental sciences	40	42	28	25
Social sciences	30	31	18	22
Biological sciences	19	20	15	20
Mathematics	40	44	20	17
Engineering	40	47	16	16
Computer sciences	37	40	12	8

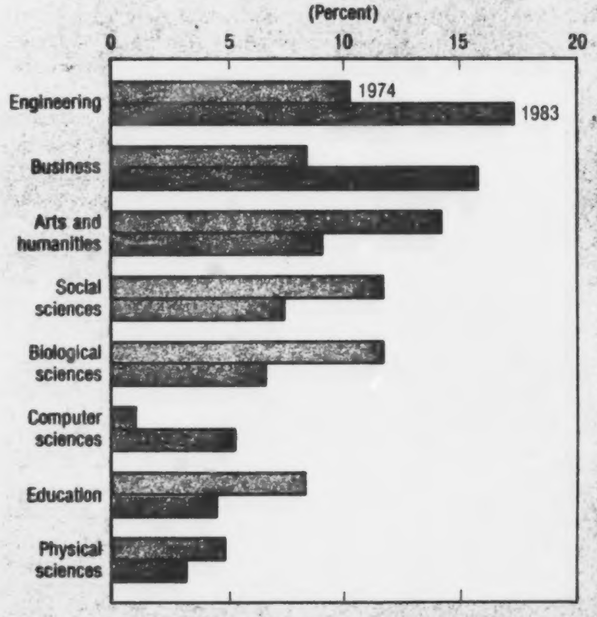
[1] Includes Ph.D. and Ed.D., only.

SOURCE: Higher Education Research Institute, Cooperative Institutional Research Program, unpublished tabulations, 1984.

Science Indicators—1985

Figure 5-6

Probable major field of first-time, full-time freshmen with "A" high school grade point average, by selected field.



See appendix table 5-10.

Science Indicators—1985

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[28] This trend has been addressed in the report of the Study Group on the Conditions of Excellence in American Higher Education (1984). See also, Bowen (1984).

[29] An exception is education, where the proportion of students selecting that professional field declined.

[30] This includes M.D., D.D.S., and other health professional degrees. Nursing is not included in this calculation.

[31] See Andersen (1984), Atelsek (1984), and National Science Foundation (1985a).

[32] Higher Education Research Institute, unpublished tabulations. "A" includes average grades of A+ to A-, and is presented in such terms in the questionnaire. See Astin (1982).

of high school physical science studies, compared to one-fifth of students intending to major in other areas. Similar differences were also apparent among S/E component fields.

In conclusion, the proportion of first-time, full-time freshmen intending to major in science or engineering in 1983 had not changed substantially from the proportion observed in 1974 (30 percent). What has changed, however, is the mix of intended S/E majors. In 1983, engineering surpassed the social sciences and the biological sciences as the most popular selection of probable major field among the sciences and engineering by entering freshmen. Furthermore, student interest has shifted away from the basic science areas and a substantial decline has occurred in the proportion of probable S/E majors planning work in the health professions.

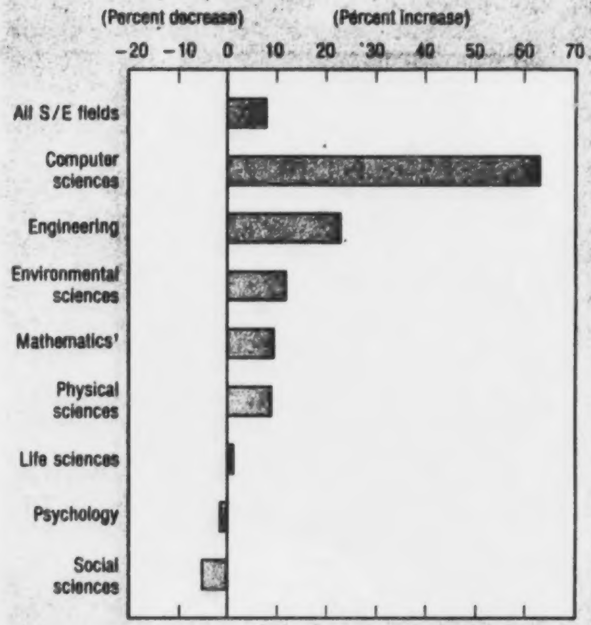
Graduate Enrollments in Science and Engineering.

Over 400,000 individuals were enrolled in graduate study in science or engineering in fall 1983, representing an increase of about 8 percent over the level enrolled in fall 1980 and 18 percent over fall 1975. The greatest growth between 1980 and 1983 occurred in the computer sciences, which nearly doubled enrollments (from 13,600 students in 1980 to 23,800 in 1983).[33]

The primary locus for graduate training in science and engineering in the United States is the doctorate-granting institution. In 1983, these institutions accounted for 87 percent of all graduate S/E enrollments, and 92 percent of all full-time graduate S/E enrollments. Between 1980 and 1983, S/E enrollments at these institutions grew by 7 percent, although this growth varied across fields. (See figure 5-7.) By 1983, graduate enrollments in engineering represented 24 percent of all S/E graduate enrollments in doctorate-granting institutions. Enrollments in the social sciences accounted for another 21 percent, followed by the biological sciences (12 percent) and the health sciences (11 percent).[34] In the computer sciences, total S/E enrollments increased from 3 percent in 1980 to 5 percent in 1983.

Figure 5-7

Percent change in S/E graduate enrollments in doctorate-granting institutions by field: 1980-83



¹Includes statistics.

SOURCE: National Science Foundation, *Academic Science and Engineering: Graduate Enrollment and Support, Fall 1983* (NSF 85-300).

Science Indicators—1985

Two trends are of particular interest for understanding the changes underway in graduate S/E enrollment patterns. The first of these is the growth in the number of women enrolled in S/E graduate education. The number of women enrolled on a full-time basis in doctorate-granting institutions increased by 7 percent between 1980 and 1983, thus extending a growth trend which began in the 1970's.[35] As figure 5-8 illustrates, the rate of growth in female, full-time S/E graduate enrollments between 1980 and 1983 exceeded that for men in each major S/E field. The greatest growth in the number of female, full-time S/E graduate students occurred in the computer sciences, followed closely by engineering and the physical sciences. By 1983, women accounted for 24 percent of total full-time graduate enrollments in the computer sciences (up from 21 percent in 1980), 11 percent of the engineering enrollments (up from 9 percent) and 19 percent of the physical sciences enrollments (up from 16 percent). In certain fields, such as psychology, the growth in the number of female full-time graduate students offset the decline which might have otherwise occurred in total enrollments in that field as a result of the decline in male enrollments.

The number of foreign students enrolled in S/E training in the U.S. has also grown.[36] By 1983, nearly 60,000 foreign students were enrolled on a full-time basis in graduate S/E programs in doctorate-granting institutions, representing 25 percent of all full-time S/E students. As figure 5-9 reveals, the lion's share of those students were enrolled in engineering (38 percent), followed by the social sciences (18 percent), mathematics and computer sciences (12 percent), and the physical sciences (11 percent).

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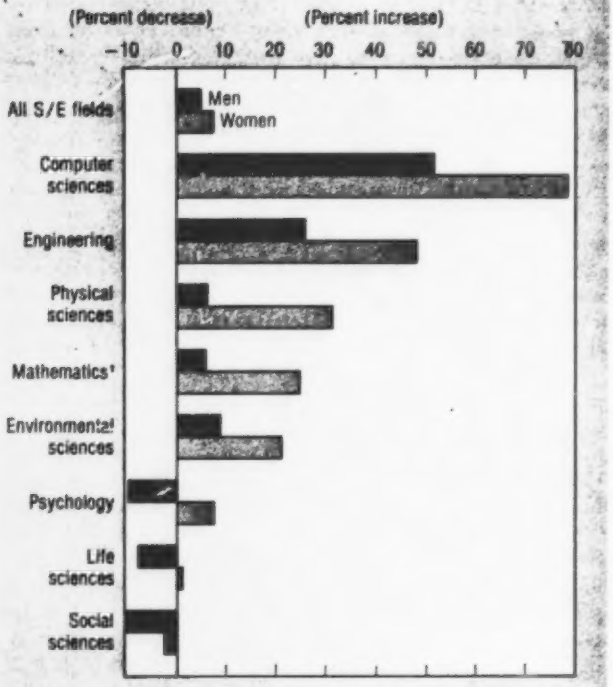
[33] See National Science Foundation (1984b), p. 60. This represents S/E graduate enrollments in both doctorate-granting and master's-granting institutions.

[34] See National Science Foundation (1984), op.cit.

[35] One of the most dramatic features of graduate enrollment growth in the last decade has been the trend for more women to select S/E degree training. This has made possible the growth in the number of women in S/E employment. However, women are more likely than their male S/E counterparts to be unemployed and seeking employment, and less likely to hold jobs in science or engineering. See, for example, National Research Council (1983) and National Science Foundation (1984b). See also the chapter in this report on S/E personnel.

[36] A number of reports have addressed the economic and educational implications of foreign student enrollment growth in U.S. graduate education. Among the more recent are: American Council on Education (1982), Goodwin and Nacht (1983), and National Science Foundation (1985b).

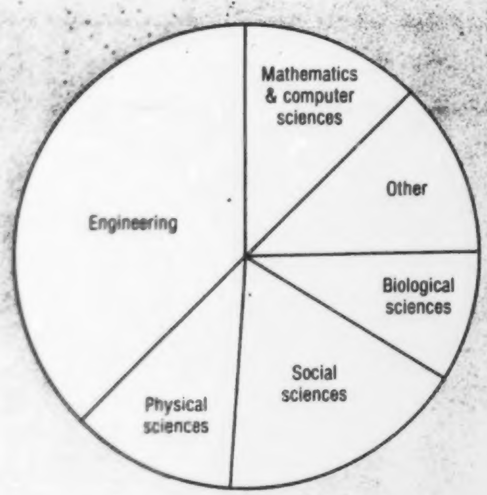
Figure 5-8
Percent change in male and female full-time S/E graduate enrollments in doctorate-granting institutions by field: 1980-83



[1]Includes statistics.
See appendix table 5-12.

Science Indicators—1985

Figure 5-9
Foreign students in full-time graduate study in science and engineering by field: 1983



See appendix table 5-13.

Science Indicators—1985

Growth in foreign student participation in S/E graduate education continues to exceed that of U.S. citizens.[37] Between 1980 and 1983, total full-time graduate S/E enrollment in doctorate-granting programs grew by 6 percent. The rate for the foreign student component was 23 percent, while that for U.S. citizens was just over 1 percent. (See figure 5-10.)[38] Foreign student participation thus accounted for 85 percent of the net growth in the number of full-time S/E graduate students in doctorate-granting institutions between 1980 and 1983.

The rapid growth of foreign graduate enrollments in certain fields has meant that foreigners are constituting increasing proportions of the total enrollments in those fields. Thus, by 1983, foreign students represented 42 percent of all full-time graduate enrollments in engineering, 40 percent in mathematics, 38 percent in the computer sciences, and 29 percent in the physical sciences.[39]

Foreign student enrollment growth has not been uniform when examined by quality of S/E program. (See appendix table 5-14.) Growth has occurred largely in lesser-rated or non-rated institutions. In 1983, one-third of the foreign students enrolled in full-time graduate study in mathematics/computer sciences were enrolled in one of the top-25 percent R&D institutions in those fields, down from a proportion of about 44 percent in 1975. Fields vary with respect to this pattern of growth.

Support for Science and Engineering Graduate Students

Most S/E students receive some form of financial assistance during the course of their graduate training. In 1983, over two-thirds of the full-time S/E graduate students in doctorate-granting institutions had such support. (See appendix table 5-15.) Among the various mechanisms of support in 1983, teaching assistantships were the most prevalent (24 percent of the full-time S/E enrollment used such support), followed by research assistantships (22 percent), and fellowships/traineeships (15 percent). In 1983, nearly one-third of the full-time S/E graduate students used "self-support" as the primary mechanism of support. Students

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[37] Also see the chapter in this report on international science and technology for a discussion of the role of the university in international S/T relations.

[38] See National Science Foundation (1984b), pp. 99-100.

[39] These are the four fields with the greatest share of foreign students. Data for the remainder of the fields are provided in National Science Foundation (1984b), pp. 101 and 140, and in National Science Foundation (1985b).

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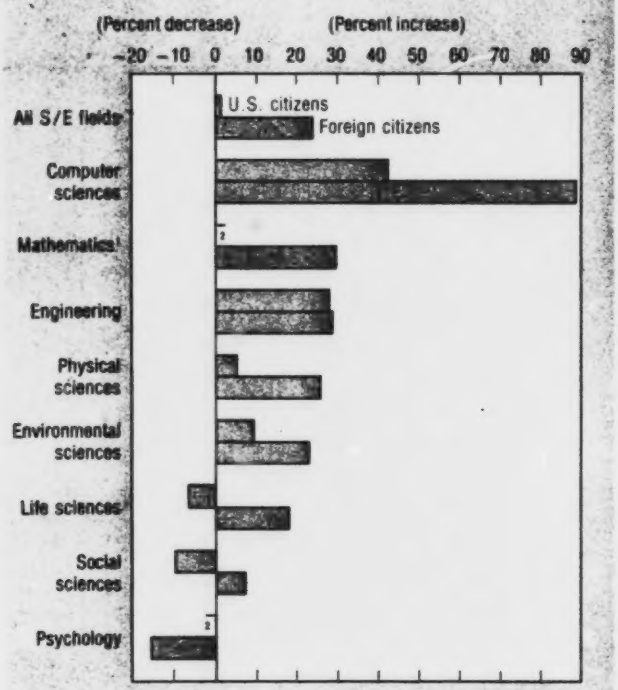
Figure 5-10

Percent change in the number of full-time S/E graduate students in doctorate-granting institutions by citizenship: 1980-83



[1] Includes statistics.

[2] Less than 0.5 percent.

SOURCE: National Science Foundation, *Academic Science and Engineering: Graduate Enrollment and Support, Fall 1983* (NSF 85-300).

Science Indicators—1985

who borrow money for graduate study are included in this category.[40]

Concern has been expressed about reductions in Federal funding for research training in science and engineering.[41] Between 1980 (the most recent peak year) and 1983, the number of full-time S/E students receiving Federal support declined by about 10 percent, or about 6,000 individuals. Much of this decline was related to a decline in funding through NIH and Federal agencies other than NSF and DOD.[42] (See appendix table 5-16.)

The decline in Federal support for training has occurred as a result of the substantial reduction in support through fellowships and traineeships. (See figure 5-11.) Between 1975 and 1983, the number of full-time S/E graduate students with Federal fellowship or traineeship support declined by 34 percent, while those having Federal research assistantships increased by 25 percent.[43] Reductions in fellowship/traineeship support have occurred in every field of science and engineering. In several areas, however, the declines have been compensated by an expansion of research assistantship support. An exception is evident in the fields of psychology and the social sciences, where such compensatory support has not been forthcoming.[44] (See appendix tables 5-15 and 5-16.)

Research training support is by no means limited to Federally funded fellowships, traineeships, or research assistantships.[45] The number of students with research training support from non-Federal sources rose about 33 percent between 1975 and 1983. (See table 5-4.) By 1983, non-Federal funding represented the primary source of research training support for full-time S/E graduate students, accounting for 53 percent of the total number of students with fellowships, traineeships, or research assistantships. More significant growth was evident for non-Federal research assistantships (up 48 percent between 1975 and 1983) than for fellowship/traineeship support (up 14 percent). (See figure 5-11.)

The reduction in Federal research training support has affected both top-rated and lesser-rated S/E departments. The number of full-time graduate students in the top 25 percent of the doctoral programs in engineering, mathematics, and the physical/environmental sciences whose primary source of support was the research fellowship or traineeship dropped from 5 percent of total graduate enrollments in those fields in 1975 to just over 2 percent in 1982.[46] However, in the biological sciences it dropped from 33 percent to 21 percent; and in the social sciences, from 14 percent to 6 percent. Although the number of Federal research assistantships grew between 1975 and 1982 in those same fields, most of the top programs had proportionately fewer students receiving Federal research training support of any kind in 1982 than in 1975.

The recent history of S/E degree production reflects renewed student interest in science and engineering. Between

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[40] For a review of the range of financial assistance available to graduate students, see Garet and Butler-Nalin (1982); Anderson and Sanderson (1982); Irwin (1983); and National Commission on Student Financial Assistance (1983). Issues related to growing student indebtedness are the subject of a number of studies including Hartle and Wabnick (1983); and Butler-Nalin, Sanderson, and Redman (1983).

[41] See, for example, National Commission on Higher Education Issues (1982); Brademas (1984); Rosenzweig (1984); and Senese (1984). Federal support for research training is provided primarily in the form of fellowships, traineeships, and research assistantships.

[42] For a discussion of labor market trends which have led to changes in student research training support by that agency and by NIH, see Institute of Medicine (1983), and earlier reports in that series.

[43] See National Science Foundation (1984b), pp. 129 and 131.

[44] In these fields, there has been a sharp decline in Federal support. In 1975, students whose primary source of support was the Federal Government represented 12 percent of full-time social science graduate students and 22 percent of all full-time graduate students in psychology. In 1982, the figures were 8 percent and 11 percent, respectively. See National Science Foundation (1984b), table C-14.

[45] Institutional and State support is largely provided through teaching assistantships. Increases in teaching assistantships, which have occurred over the years, do not compensate for losses of fellowships, traineeships, or research assistantships, since the latter support mechanisms are aimed at strengthening research skills, while the former serve as an opportunity to develop pedagogic proficiency.

[46] See Snyder (1984b).

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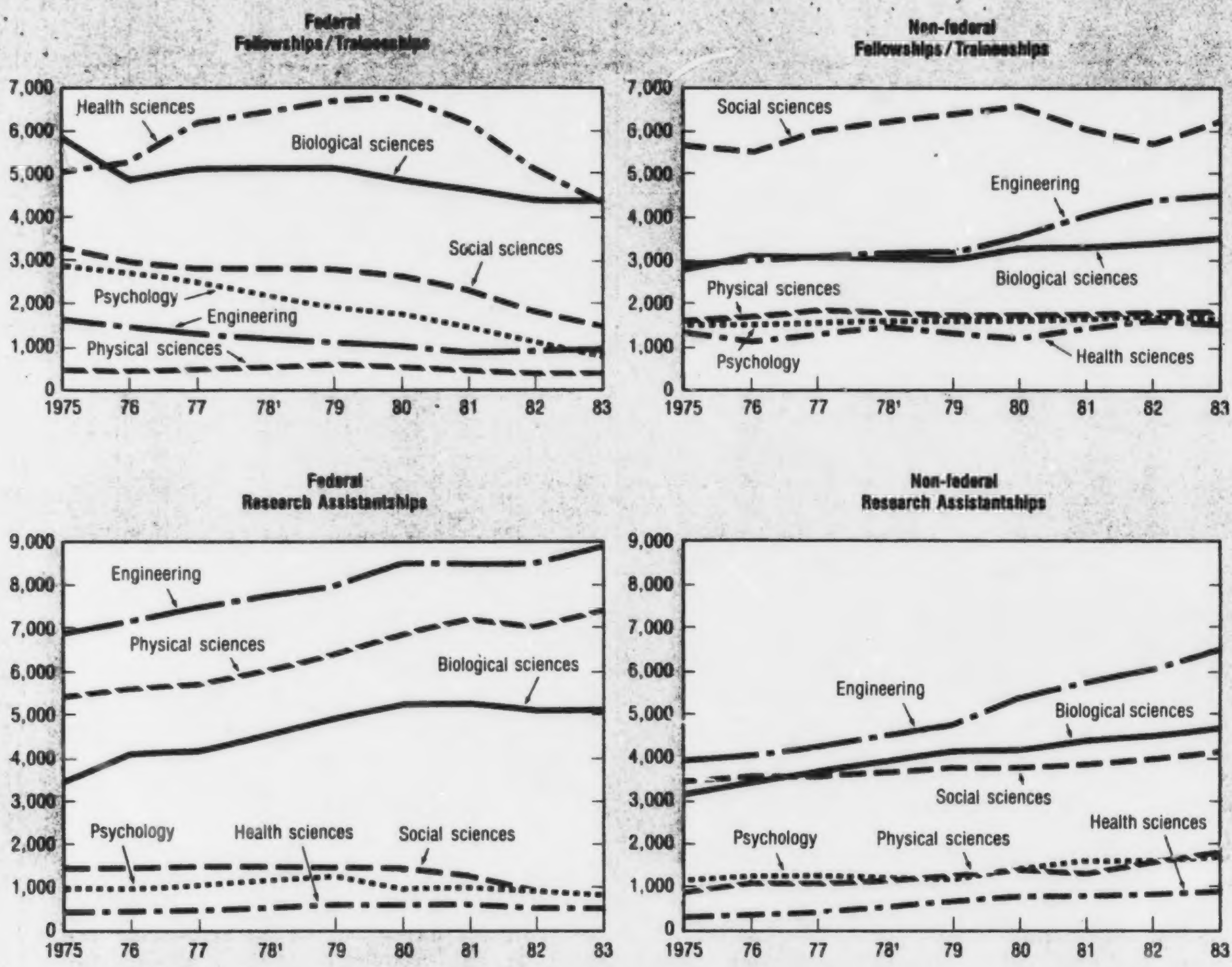
Figure 5-11

Full-time S/E graduate students with fellowships/traineeships and research assistantships by field, type and source support



¹Distribution by type of major support was not collected in 1978.

SOURCE: National Science Foundation, *Academic Science and Engineering: Graduate Enrollment and Support, Fall 1982* (NSF84-306), and unpublished tabulations.

See appendix tables 5-15 and 5-16.

Science Indicators—1985

1979 and 1982, the total number of S/E degrees awarded grew at an average annual rate of 1.5 percent, following a 5-year decline from the recent peak year of 1974. (See appendix table 5-2.) This pattern of renewed growth is evident at each degree level, as shown below.

Average annual percent change

S/E degree level	*1974-79*	*1979-82*
Bachelor's	-1.1	1.5
Master's	0.1	1.5
Doctor's	-1.7	1.1

Although the number of S/E bachelor's degrees has grown annually since 1979, trends vary among S/E fields. The most significant gains have occurred in the computer sciences and engineering, where the average annual growth rates between 1979 and 1982 were 32.0 percent and 8.0 percent, respectively. Indeed, computer science bachelor's degrees accounted for 86 percent of total S/E baccalaureate degree growth in that time. (See appendix table 5-3.)

FACULTY ROLES IN SCIENCE AND ENGINEERING

The academic sector is second only to industry in the employment of scientists and engineers at all degree levels. In 1983, educational institutions employed about 24 percent of all scientists and 3 percent of all engineers in the

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Table 5-4. Relative change in the number of S/E graduate students[1] and source of research training support[2]: 1975 to 1983

S/E field	Total S/E enrollment[1]	Number having research training support from: Federal source	Non-federal source
All S/E fields	13.0	−1.4	27.8
Engineering	32.4	10.9	49.6
Physical sciences	9.8	24.6	30.1
Environmental sciences	19.6	5.8	32.3
Mathematics[3]	−0.3	−11.7	−3.9
Computer sciences	100.0	64.3	59.3
Agricultural sciences	13.7	2.2	25.6
Biological sciences	1.2	1.5	34.1
Health sciences	29.9	2.5	50.1
Psychology	7.3	−48.4	23.9
Social sciences	−0.9	−39.8	5.7

[1] Full-time students in doctorate-granting institutions.

[2] Research training support includes fellowships, traineeships, and research assistantships.

[3] Includes statistics.

SOURCE: National Science Foundation, *Academic Science/Engineering: Graduate Enrollment and Support, Fall 1982* (NSF 84-306), pp.101, 127-132, and unpublished tabulations.

Science Indicators—1985

United States; 51 percent of all scientists and 80 percent of all engineers worked in business and industry.[47] Educational institutions are a major source of employment for doctoral S/E's. In 1983, these institutions employed about 60 percent of all doctoral scientists and about 33 percent of all doctoral engineers. Thus, of the 370,000 doctoral S/E's employed in 1983, 53 percent (196,000) were employed in educational institutions. (See appendix table 5-26.) Virtually all of the academically employed doctoral S/E's (96 percent) were employed in 4-year colleges and universities. (See appendix tables 5-26 and 5-27.)

Between 1981 and 1983, the number of doctoral S/E's employed in 4-year colleges and universities expanded by 5 percent. The greatest growth occurred in the number of doctoral-level computer scientists, which grew by 32 percent, and in the number of doctoral-level engineers, which grew by 12 percent. (See appendix table 5-27.) Low growth was observed in the remaining fields with the exception of the physical sciences whose numbers declined by nearly 2 percent between 1981 and 1983.

Important changes have occurred in recent years in the composition of the academic doctoral S/E workforce. In 1983, about one-third of the doctoral S/E's employed in 4-year colleges and universities were under 40 years of age, as opposed to 44 percent in 1977. (See appendix table 5-28.) The decline among the under-40-year-olds has occurred across all fields of science and engineering, although to varying degrees, as shown below.

Percent of academic doctoral S/E's under 40 years of age

	1977	*1983*
All S/E's	44	33
Physical scientists	45	26
Engineers	38	28
Mathematicians	53	30
Computer scientists	57	48
Life scientists	46	37
Psychologists	47	40
Social scientists	40	30

Changes in salaries of the academic doctoral S/E work force are related to changes in market conditions for doctoral S/E faculty. In 1983, engineers reported the highest median salaries at both the full-professor and the assistant-professor levels, $51,500 and $36,200, respectively. Mathematicians reported the lowest among broad S/E fields, with $38,900 for full professors and $25,000 for assistant professors. Between 1977 and 1983, median salaries for full and assistant professors in science and engineering grew by 7 percent in current dollars; however, this change actually represented a 2-percent decline when converted to constant dollars.[48] The greatest salary growth between 1977 and 1983 occurred among assistant professors in engineering, whose salary grew by 10 percent in current dollars and by 2 percent in constant dollars. Declines were evident in all other fields of science.

Changes in student enrollments, R&D funding, and university-industry linkages are responsible in part for new patterns of academic S/E employment. This section

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[47] See National Science Foundation (1985a), pp. 4 and 9, and the chapters in this report on S/E personnel and on industrial S/T.

[48] Using the Consumer Price Index and indexing 1977 as the base year.

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explores some of the changes that have occurred in the employment of the S/E faculty in recent years in response to these new teaching and research demands.

Teaching

In recent years, nearly three-quarters of academically employed doctoral S/E's reported teaching as their primary or secondary work activity—73 percent in 1981, and 72 percent in 1983. Disciplinary variations in teaching ranged from a low of 62 percent of the life scientists to a high of 88 percent for mathematicians and 84 percent for social scientists. (See appendix tables 5-27 and 5-29.)

The number of academic doctoral S/E's primarily or secondarily employed in teaching increased by 18.4 percent between 1981 and 1983. (See figure 5-12.) The greatest increase in teaching occurred among computer specialists (31 percent), reflecting the substantial enrollment growth which has taken place in that field.

In 1983, about 46 percent of the teaching academic doctoral S/E's were ranked as full professors in 1983, about the same as the 44 percent recorded in 1981. (See appendix table 5-29.) The lower proportion of full professors who teach among computer specialists is probably related to the expansion of academic doctoral S/E's in that field at the lower end of the "academic ladder." In most fields, the number of full professors engaged in teaching grew at a higher rate than the number in other academic positions, as shown below.

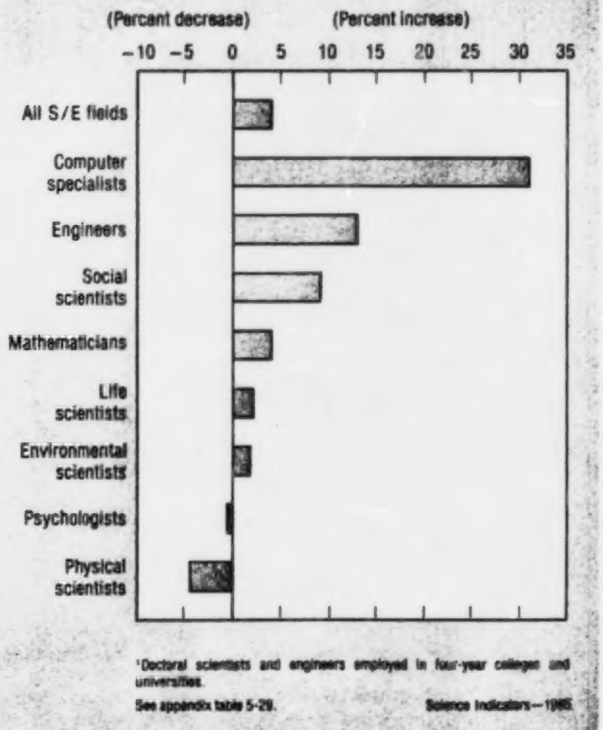
Percent change (1981 to 1983)

	Full Professors	*Other academic positions*
All S/E's	37	5
Physical scientists	31	-26
Mathematicians	39	-15
Computer specialists	53	68
Environmental scientists	11	2
Engineers	48	14
Life scientists	35	11
Psychologists	34	5
Social scientists	44	17

In some fields, such as the physical and the mathematical sciences, the number of teachers in positions other than full professors actually declined. Such changes contributed to the growth in the share of doctoral S/E's who teach and who hold full professorships in the physical sciences from 50 percent in 1981 to 60 percent in 1983, and from 40 percent in 1981 in the mathematical sciences to 47 percent in 1983. In other words, the professoriate in these fields appears to be aging.

Figure 5-12

Percent change in the number of employed academic[1] S/E's whose primary or secondary activity is teaching: 1981-1983



[1] Doctoral scientists and engineers employed in four-year colleges and universities.

See appendix table 5-29. Science Indicators—1985

Research

Slight growth (2 percent) occurred in the numbers of academic doctoral S/E's who conduct research primarily or secondarily (including management of R&D) between 1981 and 1983. In 1983, 62 percent of the doctoral S/E's employed in academia classified themselves in this category, ranging from a high of 76 percent in the environmental sciences to a low of 47 percent in the social sciences. Between 1981 and 1983, the greatest growth in the number of these academic research S/E's occurred among computer specialists, as shown below.

Percent change (1981 to 1983)

All SE's	2
Physical scientists	-5
Mathematical scientists	2
Computer specialists	23
Environmental scientists	-3
Engineers	17
Life scientists	-2
Psychologists	-2
Social scientists	7

The majority (68 percent) of academic doctoral S/E's conducting research primarily or secondarily in 1983 performed basic research. Between 1981 and 1983, the number of these basic R&D scientists and engineers grew by 3 percent, with the greatest growth occurring among engineers performing basic research (up 35 percent between 1981 and 1983). As a result of this trend, the proportion of academic doctoral engineers primarily or secondarily engaged in R&D grew from 38 percent of the total in 1981 to 43 percent of the total in 1983.

Academic doctoral S/E's performing R&D in the mathematical sciences, physical sciences, and the life sciences continue to have the highest proportion engaged in basic research—between 75 and 79 percent in 1983.

Between 1973 and 1982, the number of articles by U.S. college and university authors grew by 9 percent, although

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decreases occurred in three of the eight fields examined.[49] (See figure 5-13.) The preponderance of publication growth in the biological and medical areas is likely related to the high proportion of research scientists evident among the life scientists employed in academia and to continued funding growth in those fields during that period. The annual number of journal-based articles by academic authors in those fields also revealed the highest growth rates during this 9-year period, rising 24 percent in biomedicine, 21 percent in clinical medicine, and 11 percent in biology.

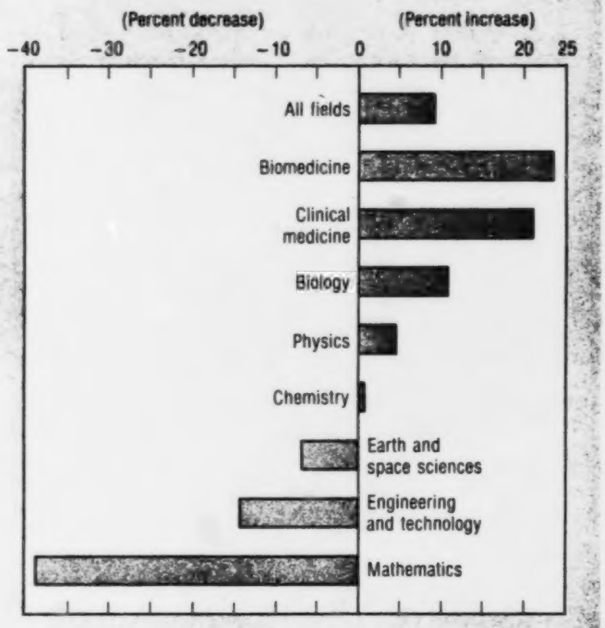
Service

A significant element in stronger university/industry ties is the practice of consulting by academic S/E's. University policies commonly permit 1 day per week consulting to provide professors with a mechanism to supplement their income, to provide a channel for bringing industry research projects to the university, and to maintain a communications network between the university and industry.[50] Nonetheless, as figure 5-14 reveals, consulting remains a considerably more modest share of total work time among doctoral S/E's.[51]

In 1983, less than 5 percent of total work time was spent on average in consulting (including professional services to individuals) by full-time faculty employed at 4-year colleges and universities (including medical schools). The proportionately higher rate of consulting time observed for psychologists (10.4 percent on average) is most likely linked to the professional services offered by academically-employed clinical and counseling psychologists. Similarly, clinical services most likely also explain some of the consulting time reported by life scientists.

A recent survey of consulting behavior among full-time S/E faculty engaged revealed that faculty employed in doctoral granting universities were more likely to have engaged in consulting than full-time S/E faculty employed by other

Figure 5-13
Percent changes in the number of science and technology articles[1] by U.S. college and university authors by field[2]: 1973-82



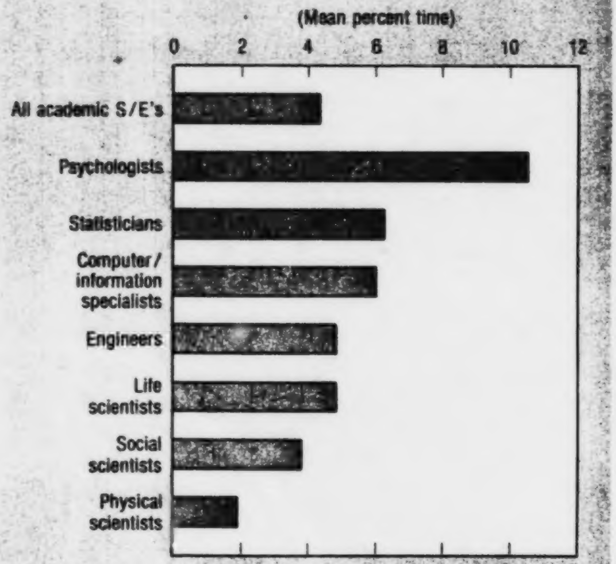
[1] Based on the articles, notes and reviews in over 2,100 of the influential journals on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2] See appendix table 1-8 for the subfields included in these fields.

See appendix table 5-31.

Science Indicators—1985

Figure 5-14
Mean percent time in consulting or professional services of doctoral S/E's employed full-time in 4-year colleges and universities[1] by selected field: 1983



[1] Includes medical schools.

SOURCE: National Science Foundation, unpublished tabulations, 1984.

Science Indicators—1985

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[49] The research literature indicators presented here are based on articles, notes, and reviews from over 2,100 highly cited or influential journals. The same set of journals has been examined for the 1973-1982 period so that longitudinal comparisons could be made without the artifact of a change in level of research coverage. See appendix table 1-7 for a summary of world trends.

[50] This policy was found to exist in 62 percent of the colleges and universities studied by Peters and Fusfeld (1982), p. 89.

[51] Peters and Fusfeld (1982) report that consulting in business schools generally occurs at a much higher rate than in either engineering schools or science departments. See also Kruytbosch and Palmer (1979).

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kinds of academic institutions.[52] Differences were evident among fields. (See appendix table 5-32.)

Numerous benefits accrue from faculty consulting, including the connections established between the campus and private industry which lead to educational and employment opportunities for S/E graduates. Familiarity with departmental activities may also lead companies to donate materials or equipment for academic R&D activities or to provide direct support for R&D. As table 5-5 indicates, faculty consulting in most S/E fields is reported to have led chiefly to jobs for departmental graduates. Equipment donation has also apparently been an important byproduct of consulting in engineering and in the biological and the physical sciences. Together with the enhanced R&D funding, the benefits which campuses have enjoyed from faculty consulting are likely to lead to a continued role for this activity.

ACADEMIC RESEARCH AND DEVELOPMENT

The changing context of U.S. science and technology influences the conduct of research in colleges and universities. An example is the formation of new university-industry research arrangements in response to industry's increasing need for a strong science base.[53] This section describes some of the changes that have occurred in the organization of R&D on our Nation's campuses.

Patterns of Academic Research and Development Funding

Virtually all separately-budgeted academic R&D activities are carried out in a relatively small group of colleges and universities. In 1983, 300 institutions, out of more than 2,000, accounted for 99 percent of total academic R&D activities, or $7.68 billion out of $7.74 billion.[54] Further, academic R&D is concentrated in doctorate-granting institutions. In 1983, just 100 of these universities accounted for 84 percent of total R&D expenditures, a proportion which has remained essentially unchanged over the years.

National support for academic R&D has reached historically high levels in current dollars in recent years. (See figure 5-15.) In 1985, an estimated $9.6 billion was spent in support of academic R&D. In constant-dollar terms, national expenditures for academic R&D grew by 7 percent between 1984 and 1985, from about $3.8 billion to $4.1 billion. This represented a substantial acceleration of the constant dollar growth rate which had been expanding at about 2.8 percent per year between 1980 and 1985.

The primary source of R&D support in U.S. academic institutions is the Federal Government. In 1985, Federal funding provided 66 percent of total R&D expenditures in those institutions, down from 68 percent in 1980. The declining share of Federal funding among total academic R&D expenditures is related to the relatively greater growth of academic R&D support by other sources. Between 1980 and 1985, Federal R&D expenditures grew at an annual rate of 2.6 percent in constant dollars. (See appendix table 5-20.) In that same period, academic R&D expenditures from industrial sources grew at an average annual rate of 9.4 percent, while those from universities' own funds grew at a yearly rate of 5.7 percent. As a result of the substantial growth of its contributions, industrial sources contributed 5 percent of total R&D expenditures reported by academic institutions in 1985, up from a level of 3 percent 12 years earlier.

Table 5-5. Proportion of full-time S/E faculty whose paid, off-campus consulting resulted in tangible benefits for the campus, by field and type of benefit: 1984

S/E fields	Type of Benefit				
	Donations of:			Jobs for:	
	Equipment	Materials	Funding	Students	Graduates
			(Percent)		
All S/E fields	36	38	50	55	50
Physical sciences	41	34	50	45	47
Environmental sciences	41	47	63	70	63
Mathematics/statistics	14	22	35	44	35
Biological sciences	33	42	46	51	46
Engineering	47	43	59	65	62
Computer sciences	30	33	50	62	51

SOURCE: F. Darknell and D. Nasatir, unpublished tabulations, 1985.

Science Indicators—1985

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[52] Darknell and Nasatir, forthcoming.

[53] David (1984) has observed that these funding changes are not new. What is new is the dramatic expansion of the interaction between university and industry, the greater involvement of students, and the greater degree of cooperation between industry and academic scientists.

[54] See National Science Foundation (1984c), pp. 14 and 17, and appendix table 5-19 of this report.

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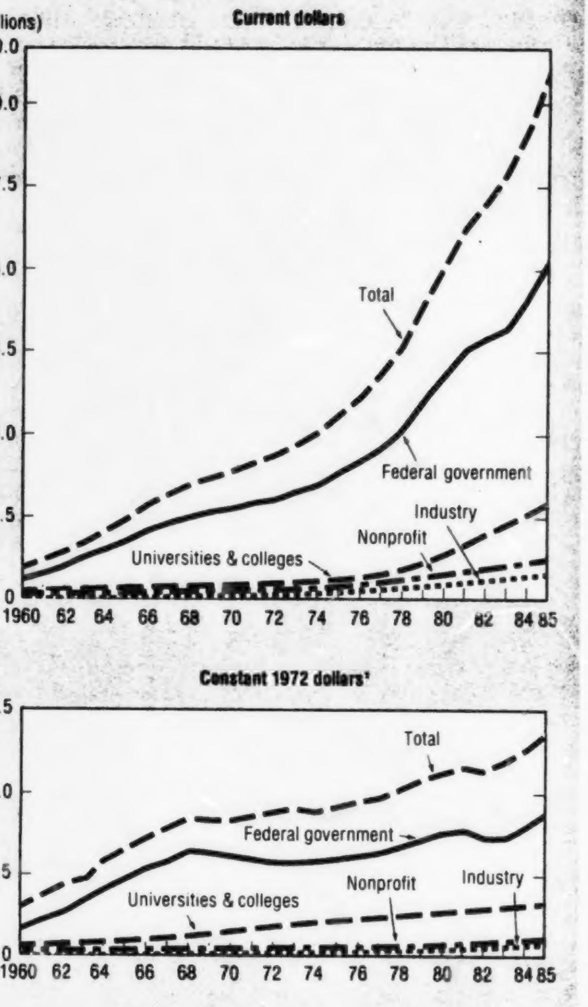
In recent years, Federal R&D policy has sought to increase funding for basic research, especially in the university sector.[55] In addition, the industrial sector is expected to expand its support for basic academic research in an effort to strengthen the science base for industrial development.[56]

Figure 5-15

National expenditures for academic R&D by source



¹GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

See appendix table 5-20.

Science Indicators—1985

As a result of these renewed funding emphases, academic expenditures for basic research are expected to grow at an average annual rate of 4.1 percent (constant dollars) between 1980 and 1985, and by 7 percent between 1984 and 1985 alone. In contrast, academic expenditures for applied R&D are expected to grow by 3.1 percent between 1980 and 1985, in constant dollars. The absence of growth in Federal support for applied R&D has contributed substantially to the differences in these anticipated growth rates, as shown below:[57]

Average annual percent change (1980 to 1984)

	Basic research	*Applied research and development*
All sources	4.1	3.1
Federal Government	3.6	—
Industry	10.2	7.3
Other sources	4.6	7.7

By 1985, basic research is expected to represent about 68 percent of total academic R&D expenditures, up slightly from a level of 66 percent in 1980, but still considerably below the level of 77 percent observed in 1972.

As Federal support for academic basic research has grown, preference has been given to the support of research in engineering, mathematics, and the computer sciences. (See appendix table 5-21.) Related to this is the differential growth evident in the basic research funding trends of the various Federal agencies.[58] Between 1980 and 1985, DOD support for basic research in academia grew at an average annual rate of 10.3 percent in constant dollars, well ahead of the 5.3 percent rate for Federal support of academic basic research as a whole. Other differences were evident across agencies, as shown below:[59]

Percent change (1980 to 1985)

All Federal agencies	5.3
USDA	5.4
DOD	10.3
NIH	6.4
NSF	3.5
NASA	3.8
Other agencies	3.8

There has been little impact as yet of these changes in Federal basic research funding priorities on the relative mix of agency support. (See figure 5-16.) NIH continues to be the predominant source of Federal basic research support in U.S. colleges and universities.

University-Industry Research Relations

Over the years, an American system of university-industry research connections has developed that is without parallel in the world. The system is complex, involving individual, institutional, and corporate responses to perceived needs and opportunities. Industrial interaction may consist of

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[55] See, for example, Keyworth (1984) and Executive Office of the President (1985) for a statement of Federal policies in this area.

[56] Growth is also expected in industrial support for basic research in the university sector. In 1980, 57 percent of industrial support of academic R&D represented funding for basic research; in 1984, estimates were 61 percent. See National Science Foundation (1984e). For a discussion of the reasons behind industrial support of academic R&D, see: Botkin, et. al. (1982); Business-Higher Education Forum (1983); David (1984); and Langenberg (1984).

[57] See National Science Foundation (1984e).

[58] See Executive Office of the President (1984), p. K-6. Emphasis has been placed on Federal support of basic research through "agencies supporting primarily physical science and engineering." These include NSF and DOD. More modest growth has been proposed for agencies such as NIH which primarily support life sciences and other basic research.

[59] In constant 1972 dollars. See appendix table 5-22.

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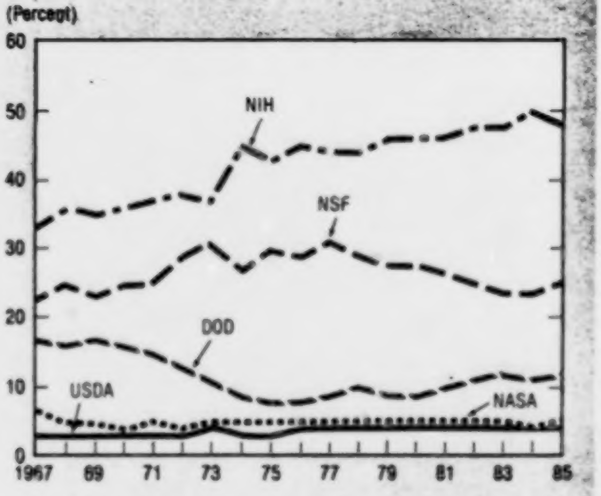
Figure 5-16

Relative distribution of Federal obligations for basic research in universities and colleges by selected agencies



See appendix table 5-22.

Science Indicators—1985

general research support to colleges or universities in the form of monetary gifts, equipment donations, endowment funds, or the construction of research facilities. It may also take the form of cooperative research support through research consortia, cooperative research centers, and university-based institutes serving industrial needs.[60]

The structural antecedents of many of today's campus arrangements for university-industry interaction may be found in the land-grant system. These institutions were established specifically to promote the linkage of applied, problem-focused research with the teaching functions of higher education.[61] With the formal creation of the agricultural experiment stations at land-grant colleges and universities in 1887, a mechanism was put into place for universities to incorporate R&D activities that were problem-focused, housed apart from instructional activities, and accountable to sponsors. Nearly 100 years later, organized research units number over 6,000, representing nondepartmental structures variously referred to as institutes, laboratories, centers, bureaus, and the like.[62] The majority of these units were established after 1960—about two-thirds of the units in core campus fields, and four-fifths of the medical sciences units. (See appendix table 5-23.)

Centers, institutes, and other separate academic research facilities furnish means for coordinating programs to attract industry. For example, they can provide equipment or give coherence for related research efforts in a general way. A number of State Governments have worked with public universities in recent years to set up organized research programs aimed at attracting industrial funding, thereby promoting State economic growth.[63]

One mechanism is the "research incubator," a research facility that provides low-cost physical space, equipment, and technical services as well as access to technical and management expertise to new start-up businesses. Most are affiliated with universities, although some are privately-owned. A recent survey of the 50 states revealed that nine such university-based facilities were in place by 1983, with another nine being planned.[64] (See table 5-6.)

The research park is another mechanism increasingly adopted to develop closer university-industry research linkages. Research parks are designed primarily to attract private industry by creating settings not unlike university campuses within which collaborative research can take place. As table 5-6 suggests, the number of parks is expected to double from 1983 levels during the next few years, as States implement plans for establishing these research entities.[65]

The Federal Government has also contributed significantly to the promotion of university-industry research relations. Through R&D tax credits, the modification of antitrust laws to permit the formation of cooperative research ventures, and changes in the patent system, the Federal Government has created a climate in which greater private sector support of university R&D might take place. Another mechanism which has received considerable attention in recent years is the cooperative research center. Federal support through these institutional structures has thus far been limited largely to that provided by the National Science Foundation.[66]

In summary, substantial changes have taken place in the organization of academic R&D, to make it more responsive to industrial research needs. These changes may be

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[60] In 1980, the National Science Board commissioned a number of background studies on the university-industry interface. Many of the papers which resulted contributed to a better understanding of the extent and variety of the interactions through case studies. See, for example, Peters and Fusfeld (1982) and Thackray (1982). Also see the chapter in this report on industrial science and technology for a discussion of university-industry interaction from an industrial perspective.

[61] More specifically, the land-grant institutions were created to encourage the "liberal and practical education of the industrial classes in all pursuits and professions of life." See Friedman and Friedman (1982).

[62] See Teich (1980); Bowen (1981); Friedman and Friedman (1984); and Haller (1984). The Directory of Research Centers listed over 6,000 such units in 1983, but this is believed to be an underestimate of the true population.

[63] State-level task forces, boards, and commissions are frequently used by Governors to plan, develop, and implement strategies like these to promote high-technology development in a direction suited to the State's existing industrial base. See Task Force on Technological Growth (1983); and Office of Technology Assessment (1984).

[64] See Task Force on Technological Innovation (1983), pp. 73-76. In 1984, Cornell University provided an update of the various university-industry research arrangements. See Haller (1984).

[65] There are many other ways in which states have strengthened university-industry linkages beyond the establishment of organized research units or parks. Through venture capital activities, for example, States can provide funds for start-up activities for spin-off firms originating in the university sector. The reports of the Task Force on Technological Innovation (1983), the Office of Technology Assessment (1984), and Cornell University (Haller, 1984) identify some of the mechanisms presently in use at the state level.

[66] See the chapter in this report on national support for R&D for a discussion of the Federal role in developing industry-university cooperative research centers. NSF has extended support to include engineering research centers which house cross-disciplinary research and teaching activities. See National Academy of Engineering (1984). For a discussion of Federal cooperative research efforts, see Konkel (1982); Tornatzky, et al (1983); and Johnson, et al. (1984).

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Table 5-6. Selected State initiatives for university-industry interaction: 1983

Type of initiative	Year of initiative: Before 1980	1980	1981	1982	1983	Initiative planned	Total number of States
Research incubators	2	4	—	4	6	5	21
Research parks	4	—	—	1	2	9	16

SOURCE: National Governor's Association, *Technology and Growth*, Appendix, 1983.

Science Indicators—1985

expected to continue as both State and Federal Governments encourage the formation of research arrangements suitable to university-industry interaction.

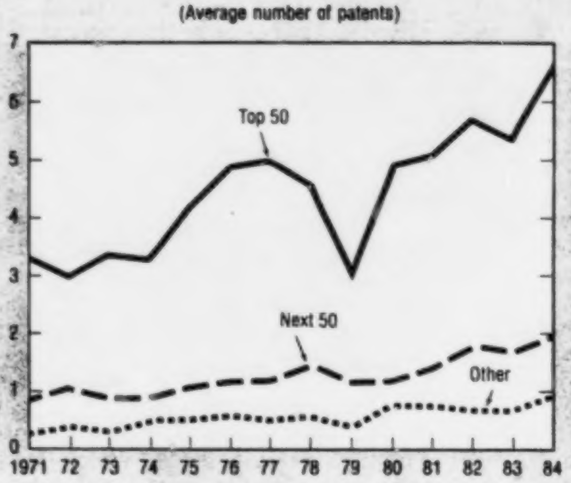
Commercialization of Research Results

Another aspect of the change that has come about in the organization of academic R&D is the expansion of patenting and licensing activities on U.S. campuses. A major stimulus was the enactment of the U.S. Patent and Trademark Amendments of 1980, which provide contractors with an incentive to bring the products of Federally-funded research to commercial use.[67] About half the top 100 academic R&D institutions had modified their patent policies sometime between 1981 and 1984 in an effort to respond more effectively to new opportunities for patenting and licensing.[68]

Between 1980 and 1983, the number of U.S. patents issued to U.S. academic institutions grew by 10 percent, increasing from a total of about 380 in 1980 to approximately 430 in 1983.[69] The number of patents issued to the top 50 R&D institutions grew at an average annual rate of 17.1 percent between 1980 and 1983. For the next 50 R&D institutions, the rate was about 15.5 percent. For all other academic institutions, the number of patents granted each year between 1980 and 1983 remained essentially constant. (See figure 5-17.)

Figure 5-17

Average number of patents issued to U.S. universities by R&D rank of institution[1] and year of grant



[1]Ranked by total R&D expenditures in FY 1983.

SOURCE: U.S. Patent and Trademark Office, unpublished tabulations, 1985.

Science Indicators—1985

Although many U.S. universities attempt to market inventions arising from research, few have the resources to patent and license them beyond U.S. borders. Worldwide patent coverage is expensive and few universities are willing to opt for more than domestic coverage.[70] Cost is not the only factor, however, in the disinclination of U.S. universities to patent at home or abroad. Another factor is the tendency of faculty to use scholarly publications as a mechanism to disseminate research findings. The decision to publish

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[67] Public Law 96-517. Section 6 established a uniform policy for assigning title to inventions made by small businesses or nonprofit institutions—including academic institutions—during Government-sponsored research.

[68] Only two of the top 100 R&D institutions (as ranked by total R&D expenditures in 1982) had no patent policy as of spring 1984. The revisions introduced into existing policies frequently simplified in-house arrangements for the review of patent proposals from faculty, or adjusted the method for distributing royalty income. See Ebert-Flattau (1984). The total number of academic institutions with patent policies is not known. However, the Society of University Patent Administrators reported more than a doubling of membership between 1982 and 1984 as colleges and universities beyond the top 100 R&D institutions sought to establish formal patenting and licensing arrangements for the first time. See Blaylock (1984).

[69] The source of these data is the Office of Technology and Forecast of the U.S. Patent and Trademark Office. Because academic institutions frequently use the services of patent management organizations, data were augmented by patent reports provided by the Research Corporation and University Patents, Inc., two of the larger patent management organizations representing academic clients.

[70] The Research Corporation estimates that in addition to the $5-10,000 required to prepare and file for U.S. patents, it cost another $15-20,000 to file for protection in Canada, Japan, and the Common Market countries in 1984. See Bacon (1984).

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forecloses the possibility of protecting an invention in most of the world. Nonetheless, evidence for increased patenting activity on U.S. campuses suggests that the commercialization of research results is a growing option among academic researchers and their institutions. In exercising this option, it will become important for universities to ensure that their patents are vigorously developed, including the pursuit of foreign patent protection wherever possible.[71]

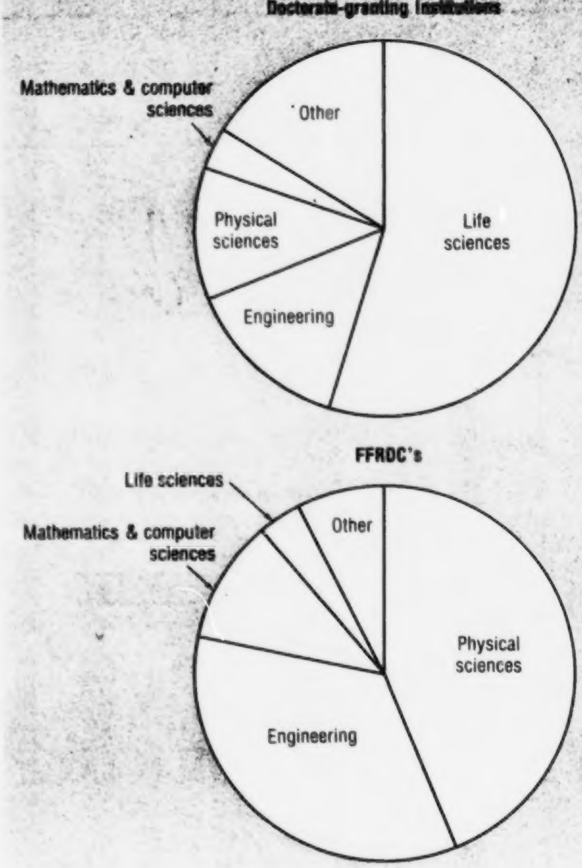
University Administered Federally Funded Research and Development Centers (FFRDC'S)

A small but important number of universities, such as Princeton, Stanford, the University of Chicago, and several consortia, serve as managers of FFRDC's.[72] Because FFRDC's often share faculty with S/E departments and make advanced research facilities available to investigators on a local as well as a national basis, it is instructive to consider how trends in the growth of R&D expenditures at these FFRDC's compare to national support for R&D at U.S. colleges and universities.

In 1983, R&D expenditures at the 19 university-administered FFRDC's totaled over $2.7 billion (see appendix table 5-24), slightly more than the amount of Federal support reported by the top 20 doctorate-granting institutions that year.[73] As figure 5-18 indicates, R&D expenditures at these FFRDC's primarily support work in the physical sciences (53 percent of the funds), while R&D support in doctorate-granting institutions emphasizes work in the life sciences (55 percent of the funds).

Between 1980 and 1983, R&D expenditures at the FFRDC's grew at an average annual rate of 5.0 percent compared to a rate of 9.5 percent for R&D expenditures at doctorate-granting institutions. (See figure 5-19.) FFRDC's emphasized R&D funding growth in mathematics and the computer sciences, which grew at an average annual rate of 16.3 percent between 1980 and 1983. By 1983, 48 percent of R&D expenditures in mathematics and computer sciences were spent through university-administered FFRDC's, up from earlier levels of 38 percent in 1972 and 46 percent in 1980. Other fields in which a sizable share of academic R&D expenditures were spent through these FFRDC's in 1983 include: the physical sciences (62 percent), engineering (38 percent), and the environmental sciences (23 percent).

Figure 5-18
Relative distribution of R&D expenditures at doctorate-granting institutions and university-administered FFRDC's[1] by field: 1983



[1]Federally-funded research and development centers.
See appendix tables 5-19 and 5-25.
Science Indicators—1985

The R&D activities of the FFRDC's are typically less basic than the R&D activities carried out in the S/E departments of doctorate-granting institutions. In 1983, two-thirds of the R&D expenditures in university-administered FFRDC's were spent for applied R&D; the comparable level observed in doctorate-granting institutions was only one-third. (See appendix tables 5-19 and 5-25.)

In January, 1983, the 19 university-administered FFRDC's employed 15,000 full-time S/E's, or 20 percent of all S/E's engaged in R&D at doctorate-granting universities and FFRDC's combined.[74] In 1983, about one-third more was

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[71] A statement issued at the conclusion of a conference of university presidents and industrial executives emphasized the desirability of pursuing patents and licenses not only to promote the public interest, but also to further rights of royalty income. Conferees warned, however, that professors may choose to delay publication of research findings for a brief period to permit prior filing of patent applications. However, without a contractual obligation, universities should not try to prevent faculty from publishing or disclosing their research findings to preserve the universities' patent rights. See Bok, et al. (1982).

[72] To be classified as a FFRDC, an organization primarily performs basic research, applied research, development, or management of R&D on direct request of the Government or under broad charter from the Government. A FFRDC is also organized as a separate entity within a parent organization, receives its major financial support (70 percent or more) from the Federal Government, has or is expected to have a long-term relationship with its sponsoring agency, is established in such a way that most or all of the facilities are owned or funded by the Government, or has an average annual budget of at least $500,000. See National Science Foundation (1984e), and appendix table 5-24 of this report for a list of university-affiliated FFRDC's.

[73] In 1982, the top 20 academic institutions (as ranked by total R&D expenditures) reported a total of $1.9 billion in federally financed R&D support. See National Science Foundation (1984c), p. 47.

[74] See National Science Foundation (1984d), pp. 26 and 74. In 1983, approximately 59,000 full-time equivalent S/E's were employed in R&D at doctorate-granting institutions.

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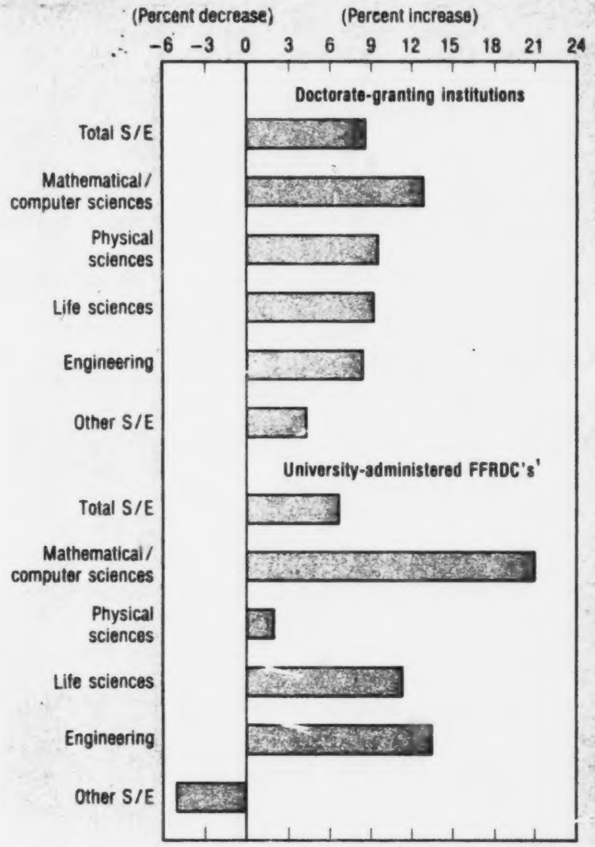
Figure 5-19

Average annual percent change in R&D expenditures at doctorate-granting institutions and university-administered FFRDC's[1] by field: 1980-83



[1] Federally funded research and development centers administered by universities.

See appendix tables 5-19 and 5-25. Science Indicators—1985

spent on the R&D work of scientists and engineers employed by FFRDC's than was spent on the R&D activities of full-time equivalent S/E's doing R&D in doctorate-granting institutions. (See table 5-7.) Owing to the higher R&D costs associated with the instrument-intensive work of the physical sciences, the per capita R&D costs were significantly higher for physical scientists than for S/E's in any other field.[75]

In summary, FFRDC's play a significant role in the work of academic science and engineering. While representing 26 percent of the combined R&D expenditures of doctorate-granting institutions and FFRDC's, and 20 percent of the academic research S/E's, the university-administered FFRDC's differ in several important ways from doctorate-granting institutions. FFRDC's, for example, largely support work in the physical sciences and engineering. R&D activities in FFRDC's are more applied in their orientation. More funds are spent in FFRDC's per R&D scientist or engineer than in academic S/E programs, which is largely accounted for by the instrument-intensive work of the physical scientists employed by FFRDC's.

SUPPORTING INFRASTRUCTURE

Up-to-date facilities and instrumentation are essential to the conduct of frontier research. Improvements in scientific instrumentation can also lead to increased productivity in the industrial sector. Thus, a major incentive for obtaining state-of-the-art university research equipment is that it contributes both to the research productivity which advances science and to the innovations which more broadly benefit American industry.[76]

In recent years, concern has been expressed in the science community about the state of academic research facilities.[77] The growing costs of conducting research have led many research managers to divert funding from facility maintenance and improvement to the support of research projects. Some facilities, for example, need renovation to bring them into compliance with new regulatory standards in such areas as health and safety, handling of dangerous materials, and disposal of hazardous waste.[78] In some cases, facilities need to be constructed to keep pace with theoretical advances, especially computer facilities.

Between 1980 and 1983, capital expenditures for facilities and equipment for research, development, and instruction[79] in the academic sector grew at an average annual rate of 10.6 percent, reaching a total of $1.1 billion in 1983. Federal support for facilities and equipment declined 11 percent during that time, while funding from other sources rose by 46 percent. By 1983, Federal funding represented 12 percent of total academic capital expenditures for facilities and equipment, down from 19 percent in 1980. (See appendix table 5-35.)

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[75] The high per capita expenditures observed for FFRDC scientists in the "other" category was probably related to the costs associated with the computer modeling activities of social and economic scientists employed in that category.

[76] The National Science Board addressed this point in its policy statement of March 1981. See National Science Board (1981); Branscomb (1982); and Abelson (1983).

[77] Facilities include buildings, research platforms (ships, field stations, etc.) and major instruments (costing over $1 million).

[78] See, for example, Association of American Universities (1981) for a limited assessment of the research facility needs of R&D universities. Systematic information regarding the state of academic research facilities is generally lacking. However, in 1983 the Federal Government established an Ad Hoc Interagency Steering Committee on Academic Research Facilities. Preliminary work of the Committee led the National Science Board to issue a statement of concern in 1984 about the adequacy of existing facilities and to recommend that consideration be given to the development of a facilities support program in the areas of biotechnology, engineering, and advanced scientific computing. See National Science Board (1984a and 1984b).

[79] Capital expenditures for facilities and equipment include funds for fixed equipment such as built-in equipment and furnishing; movable scientific equipment such as oscilloscopes and pulse-height analyzers; and special separate facilities used to house scientific apparatus such as accelerators, oceanographic vessels, and computers. (See National Science Foundation in 1984c).

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Table 5-7. R&D expenditures per S/E[1] in doctorate-granting institutions and university-administered FFRDC's[2], by field: 1983

S/E field	Doctorate-granting institutions	FFRDC's[2]
	(Thousand dollars)	
All S/E fields	$123.5	$169.8
Engineering	153.8	99.1
Physical sciences	115.2	250.7
Environmental sciences	187.9	217.9
Mathematics/computer sciences	123.4	155.0
Life sciences	113.0	121.1
Other	99.0	229.4

[1] R&D expenditures were divided by the number of full-time equivalent S/E's employed in research and development in doctorate-granting institutions and by the number of full-time S/E's employed in university-administered FFRDC's to derive these ratios.

[2] Federally funded research and development centers administered by universities.

SOURCES: National Science Foundation, *Academic Science/Engineering: R&D Funds, Fiscal Year 1982* (NSF 84-308) and, *Academic Science/Engineering: Scientists and Engineers, January 1983* (NSF 84-309).

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This section reviews recent trends in the condition of existing scientific instrumentation and research facilities in the academic sector.[80]

Scientific Instrumentation

The single-investigator research grant is the predominant mechanism for funding the purchase of scientific instruments in the university sector.[81] In 1983, approximately 6 percent of separately budgeted R&D expenditures at colleges and universities represented research equipment expenditures. (See appendix table 5-33.) This proportion varied from 9 percent of total academic R&D expenditures in the physical sciences to 3 percent in the social sciences. The proportion of academic R&D expenditures devoted to the purchase of research equipment has remained stable in recent years.[82]

Of the $435 million spent in 1983 for the purchase of academic research equipment, $273 million (or 63 percent) represented Federal funding. Since 1980, academic research equipment expenditures from Federal sources grew at an average annual rate of 3 percent, but declined slightly as a share of total equipment expenditures (66 percent to 63 percent in 1983). Although it is too early to determine whether these data represent a stable trend, the apparent rise of non-Federal funding for research equipment seems to reflect a growing use of alternate financing arrangements for equipment purchase.[83]

Per capita research equipment expenditures (dollars per FTE research scientist or engineer) averaged about $7,200 in 1983, up from a level of $6,900 in 1982. (See table 5-8.) Equipment expenditures per FTE researcher varied from $17,400 in the computer sciences to $2,100 in the mathematical sciences.

In keeping with the higher per capita research equipment expenditures for the computer sciences, it is not surprising to learn that 78 percent of the research instruments in use in the computer sciences in 1982 were purchased since 1978. (See figure 5-20.) The median age of academic research instrument systems in the 1982 national inventory[84] was 6 years, although this varied by field: 6 years each in the physical, biological, and medical sciences; 5 years in engineering and agriculture; and 3 years in the

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[80] See the chapter in this report on advances in S&T for a discussion of the contribution of specific scientific instruments to the advancement of science in selected areas.

[81] In this discussion, scientific instrumentation includes pieces of research equipment not exceeding $1 million in cost.

[82] See, for example, National Science Foundation (1982b).

[83] Some universities are replacing obsolete equipment through tax-exempt financing, such as the issuance of revenue bonds or industrial development bonds. See Baum (1981); Olson (1984); and Sheppard (1984). The Association of American Universities is now completing a project (start in 1983) which is examining alternatives to meeting university equipment needs.

[84] In response to Public Law 96-44, the National Science Foundation is in the process of completing the tabulations from a 1982 national survey of research instruments and instrument use in 43 institutions, statistically sampled from the 157 largest academic R&D performers. The survey was designed to yield nationally representative estimates on the amount, condition, and cost of existing scientific research instrument systems in calendar year 1982. Information available to date has been published in National Science Foundation (1984g), NSF (1984h), and National Institutes of Health (1985). For a summary of the several major studies of academic scientific equipment needs, see General Accounting Office (1984).

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Table 5-8. Per capita current fund research equipment expenditures at colleges and universities per FTE[1] scientists and engineers employed in research and development, by field

S/E field	1982	1983
All S/E fields	$6,900	$7,200
Engineering	9,800	10,700
Physical sciences	10,700	11,200
Environmental sciences	9,500	10,300
Mathematics	1,900	2,100
Computer sciences	15,900	17,400
Life sciences	5,700	5,800
Psychology	3,900	4,500
Social sciences	2,000	2,500

[1] Full-time equivalent. Current fund expenditures for research equipment (see appendix table 5-33) were divided by the number of full-time equivalent S/E's employed in research in universities and colleges.

SOURCES: National Science Foundation, *Academic Science/Engineering: R&D Funds, Fiscal Year 1982* (NSF 84-308) and *Academic Science/Engineering: Scientists and Engineers, January 1983* (NSF 84-309), and unpublished tabulations.

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computer sciences. In materials science, the median age of instrument systems was eleven years.

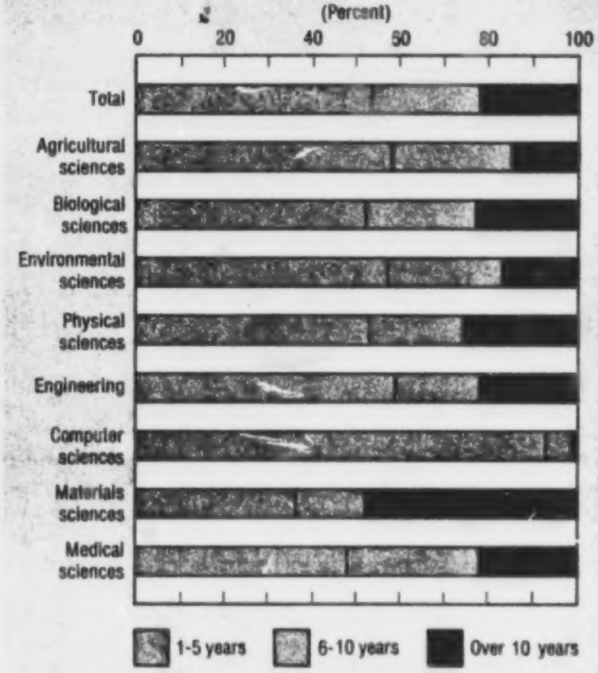
In the 1982 NSF national survey, department chairpersons were asked to evaluate the adequacy of research instrumentation to enable investigators to pursue major research interests. About 8 percent of the respondents rated the equipment situation as excellent, 46 percent as adequate, and another 46 percent as insufficient in the S/E fields surveyed. Although the computer sciences tended to have newer equipment and a greater proportion of state-of-the-art instruments, chairpersons in that field rated the adequacy of the systems lower than in the other fields.[85]

Since the supply of equipment for frontier research is limited, it is important that the available equipment be well utilized. Just over 40 percent of all in-use research equipment in the 1982 NSF inventory was located in shared-access facilities.[86] Fields with the largest share of in-use equipment in shared access facilities were the computer sciences and the materials sciences, each with 81 percent of their systems so used. The biological sciences (including that performed in medical schools) and the physical sciences had the lowest proportion of shared equipment, at a level of about one-third. (See table 5-9). These shares varied when analyzed by the status of research equipment.

The importance of computer systems in academic research and teaching is reflected in the large share of in-use equipment in shared-use facilities.[87] The use of modern computers in scientific research spans a period of only three decades, but it has been a period in which profound and rapid changes have occurred. In the 1950's and 1960's, Government support was a deciding factor in the growth of university access to computers.[88] Although most universities chose to develop computing facilities on an institutional basis, others developed shared facilities. A characteristic of all the facilities was that they were developed for multidisciplinary use—providing computing services to researchers without regard to discipline—as well as for educational use, and often for administrative applications.

Figure 5-20

Age distribution of academic research instrument systems: 1982-83



NOTE: All statistics are national estimates encompassing the 157 largest R&D universities and the 92 largest R&D medical schools in the nation. Agricultural, biological and environmental sciences estimates are as of December 1983. For all other fields, estimates are as of December 1982. Sample is 6985 instrument systems.

SOURCE: National Science Foundation, *Academic Research Equipment in the Physical and Computer Sciences and Engineering* (1985), and unpublished tabulations.

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[85] See National Science Foundation (1984g).

[86] Shared access facilities include department-managed common laboratories and national and regional laboratories. See NSF (1984h.)

[87] Computers and their related technologies have become major tools in education and in industry. The effects of this technological development are addressed in numerous publications, including: Office of Technology Assessment (1981 and 1982); McCredie and Timlake (1983); Willenbrock (1983); Arons (1984); and Gerola and Gomory (1984). Also see the chapter in this report on public attitudes toward S/T for a discussion of the public's views about computers.

[88] See National Science Foundation (1983b), pp. 3-5, for an historical review of the use of computers in the academic environment.

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Table 5-9. Percent of in-use academic research instrument systems located in shared access facilities, by research status, selected fields[1]

Field of research	Total	Research Status	
		State-of-the-art systems	Other systems in research use
	(Percent)		
Total	41	38	42
Agricultural sciences	36	31	38
Biological sciences, total	35	32	36
Graduate schools	34	29	36
Medical schools	36	35	36
Environmental sciences	48	46	49
Physical sciences	35	27	37
Engineering	50	50	49
Computer science	81	73	83
Materials science	81	73	83
Interdisciplinary, n.e.c.	73	84	68

[1] All statistics are national estimates encompassing the 157 largest R&D universities and the 92 largest R&D medical schools in the Nation. For agricultural, biological, and environmental sciences, estimates are as of December, 1983. For all other fields, estimates are as of December, 1982. Sample is 6985 instrument systems.

SOURCE: National Science Foundation, unpublished statistics.

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The horizons for the role of computing in science and engineering broadened extensively with developments which began in the 1960's to improve access to computers. Remote access, coupled with timesharing and interactive systems, permitted users who were physically remote from the computer to make concurrent use of a computer facility. In the early 1970's, some universities had the supercomputers[89] of the period. However, by the middle of the decade there were no universities with state-of-the-art supercomputers. Lacking Federal support for research instrumentation, academic facilities fell behind industrial laboratories in computing resources for research.

By December 1984, five U.S. universities had the latest supercomputers in place.[90] (See table 5-10.) These university-based supercomputers serve a variety of uses, just as the earlier campus computer facilities did.[91]

It is doubtful that due to their high cost, supercomputers will ever be as commonplace on university campuses as state-of-the-art computers were in the 1960's and early 1970's. As a result, while providing for significant increase in the acquisition of supercomputers, current Federal policy emphasizes improved access to modern computer technology through computer networking. (See appendix table 5-34.) NSF is currently the lead agency in renewed Federal efforts to strengthen the academic computing environment.[92]

Table 5-10. Installed "supercomputer" systems in the United States: 1983 and 1984

Type of installation	1983	1984 (est.)
All installations	49	56
Government research laboratories	23	26
Universities	3	5
Industry	20	22
Computing science bureaus	3	3

SOURCE: National Science Foundation, unpublished tabulations.

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[89] Supercomputers are the fastest and most powerful scientific computing systems available at any given time. For a further description of the role of supercomputers in large-scale computing, see Lax (1983).

[90] The universities with supercomputers in 1984 were: Colorado State University (Cyber 205), University of Minnesota (Cray 1), University of Georgia (Denelcor HEP), Purdue (Cyber 205), and Florida State University (Cray 1).

[91] Some Federal agencies have become off-campus users of academic supercomputers. The National Bureau of Standards, for example, has a direct line to the supercomputer at Colorado State University, thus extending the research capability of that U.S. Federal laboratory.

[92] The National Science Foundation program in advanced scientific computing was launched in April, 1984. The Department of Defense has established a program aimed at the development of strategic computers to meet DOD objectives, which will also indirectly enrich the university computing environment. Other agencies planning specialized computing programs include NASA and DOE. See NSF (1983b), p. 12.

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Because access to supercomputers through telecommunications has become a reality, Federal officials envision a national computer network which will provide access by the academic research community to multiple levels of computational resources and to large data-bases. Such a computer network is expected to reduce wasteful duplication of effort in software development.

Research Libraries

An important aspect of the academic research environment is the research library. While many American colleges have built libraries that serve as outstanding resources for research and learning, many face substantial problems in maintaining present inventories at a time of increasing costs and shrinking budgets. A recent analysis of the research libraries of the top 50 academic R&D institutions revealed that between 1980 and 1983, expenditures for library materials (other than serials) increased by 90 percent while the number of volumes added each year remained essentially constant. (See appendix table 5-36.) Although the top academic R&D performing institutions have managed to stay ahead of inflation in terms of budget size, a decline in the proportion of their collections that represents new acquisitions is evident. (See table 5-11.) Given the continuing constraints placed on academic fiscal resources, it appears likely that academic institutions with a high level of R&D activity will be challenged to sustain their growth in the coming years, a problem which libraries of lesser-ranked institutions may have already confronted.

OVERVIEW

The Nation's colleges and universities continue to play a major role in U.S. science and technology. This is evident in the higher rates of investment for R&D performed in the academic sector, up 7 percent between 1984 and 1985 (even after inflation). Increased Federal expenditures accounted for the two-thirds of this growth.

Science and engineering continue to attract talented and motivated students. However, two significant trends are evident. The first of these is the absence of growth in the number of U.S. citizens enrolled in full-time graduate study in S/E in doctorate-granting institutions. Between 1980 and 1983, total full-time enrollments in graduate S/E programs in those institutions grew by 6 percent; the rate for U.S. citizens alone was less than 1 percent. Thus, foreign student participation accounted for 85 percent of the net growth in full-time S/E graduate enrollment in doctorate-granting institutions between 1980 and 1983. The 10 percent decline in Federal support for graduate S/E research training between 1980 and 1983 may be related to the slowing of U.S. citizen enrollment in graduate S/E study.

Generally, changes in Federal research training support have occurred uniformly across the whole program quality spectrum. Thus, Federal fellowship/traineeship support declined about 45 percent between 1975 and 1982 in the top 25 percent of the rated S/E doctoral progams and by a comparable amount in the remaining S/E programs. Similarly, the 25-percent growth in the number of Federal research assistantships reported between 1975 and 1982 was spread fairly evenly between the two levels of program quality. Only in the fields of psychology and the social sciences did a substantially greater decline occur in overall graduate research training support in the top 25 percent of the top-rated programs than the decline that occurred in lesser-rated or non-rated programs.

Most S/E fields continue to draw a substantial proportion of their new Ph.D. recipients from top-rated programs. In 1983, 51 percent of the engineering graduates received their doctoral training in the top 25 percent of the

Table 5-11. Volumes added as a percent of total library collection at the research libraries of the top 50[1] academic R&D institutions: 1969 and 1980-1983

R&D Rankings[1]	1969	1980	1981	1982	1983
			(Percent)		
First 10	5.2	3.0	2.7	2.5	2.8
11-20	4.0	3.0	2.9	2.6	2.7
21-30	6.7	3.6	3.3	3.1	3.4
31-40	6.6	3.6	3.3	3.1	3.1
41-50	5.7	3.5	3.1	3.2	3.4

[1] As ranked by total academic R&D expenditures in 1982. Includes only those institutions who were member of the Association of Research Libraries in 1984. (45 of the 50 institutions)

SOURCE: Association of Research Libraries, special tabulations, 1984.

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rated programs—a level comparable to the Ph.D. production rates observed in the physical and environmental sciences and in mathematics and the computer sciences. Possibly as a result of the erosion in graduate training support for psychology and the social sciences, the proportion of Ph.D. recipients from top-rated programs declined from 40 percent of the total number of new Ph.D.'s in psychology and the social sciences in 1972 to 32 percent in 1982.

As student interest has shifted to the computer sciences and engineering, academic employment of doctoral scientists in the remaining fields has not grown on the whole, although in general no decline has occurred. This may have long term deleterious effects if demand priorities change. As the demand for research grows in fields other than engineering and the computer sciences, it will be important to assure that faculty are available in these other fields to perform research.

In recent years, U.S. colleges and universities have initiated a number of changes in the organization of science and engineering designed to foster stronger ties with the industrial sector. For example, many campuses have adopted new institutional arrangements to promote university-industry linkages for R&D purposes. They have accomplished this through the creation of research units established specifically for the performance of problem-focused research. In public institutions, this trend has been broadened by State initiatives intended to promote economic growth through increased access to academic expertise. Some of the mechanisms that have been introduced to date are research incubators and research parks.

As industrial R&D support has grown and Federal policies have changed, academic administrators have also decided to pursue patents with greater vigor than in the past, not only to promote the public interest but also to further their rights to royalty income. Although many U.S. universities have attempted to market inventions arising from research, few have had the resources to patent and license them beyond U.S. borders. It is not clear to what extent universities will be willing to elect for more than domestic coverage at this point. However, this option is likely to become increasingly important as administrators pursue the full development of patents arising from academic R&D.

Up-to-date instruments and facilities are critical elements in the performance of R&D. The level of sophistication of scientific equipment has a decisive effect on the kinds of research which can be done. Evidence suggests that scientific instrumentation and facilities will be one of the most critical problems confronting academic institutions in the coming years. Findings from a recent national inventory of academic scientific instruments revealed that 8 percent of S/E department chairpersons viewed their equipment situation as excellent, 45 percent as adequate, and another 46 percent as inadequate. Although the computer sciences tended to have newer equipment than many other fields, a greater proportion of chairpersons in that field rated instruments as inadequate than respondents from the other science fields surveyed.

Access to advanced computational facilities appears to be a major dilemma for academic researchers. While Federal programs in the 1960's permitted many institutions to acquire contemporary state-of-the-art computers, a lag in Federal program support has resulted in the emergence of only five academic institutions with state-of-the-art supercomputers at the end of 1984. Because of the high costs of these computers and of the rapid advances being made in the computer field, it is doubtful that the most advanced computers will ever be as commonplace on university campuses as state-of-the-art computers were two decades ago. As a result, Federal policies presently promote broader utilization of the most advanced computer equipment through computer networking. A national computer network is envisioned which will provide all researchers access to multiple levels of computational resources and to large data bases through telecommunications.

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Chapter 6
Precollege Science and Mathematics Education

Precollege Science and Mathematics Education

HIGHLIGHTS

- *During a time when science and technology are playing an increasingly important role in the lives of all citizens, the average high school student knows comparatively less about these subjects.* In 1982, science achievement scores of students aged 9, 13, and 17 were lower than scores in 1970. From 1977 to 1982 the only positive changes were on achievement scores of 9-year-olds. In mathematics assessments from 1973 to 1982, the performance of 9-year-olds was relatively stable; scores of students aged 13 fell slightly from 1973 to 1978, then increased 4 percentage points from 1978 to 1982; scores of 17-year-olds dropped 4 percentage points from 1973 to 1978 and then leveled off from 1978 to 1982. (See pp. 125-126.)
- *Blacks and Hispanics scored well below their white counterparts in all assessments in each year.* But in the 1977-82 science assessments, 9-year-old black students improved in performance while white students declined. Also, during 1973-82, black students and students in the lowest performance quartile improved on exercises assessing mathematics knowledge. (See p. 126.)
- *Some positive signs of performance have occurred during the latest mathematics assessments,* but most of these improvements have occurred in the knowledge, skills, and understanding of items which test a student's ability to solve routine computational and measurement problems usually associated with textbooks and learning by rote. Relatively few students perform well on problems requiring analytical skills and application of mathematics to nonroutine situations. (See pp. 126-127.)
- *The Scholastic Aptitude Tests (SAT) show that students intending to major in science or engineering (S/E) score significantly higher than other students on both the verbal and mathematics tests, averaging more than 30 scale points above the national means.* However, national SAT score means for all students declined during 1975-84 for students intending to major in science or engineering. By 1984, scores for prospective S/E majors were 13 scale points below their 1975 level on the SAT verbal test; corresponding scores dropped 12 scale points on the SAT math test. Most of the declines occurred from 1975 to 1981; in 1984, both the verbal and quantitative scores were slightly above those in 1981. (See p. 127.)
- *The proportion of students with the best quantitative ability, as indicated by SAT scores of 650 or above (of a possible 800), has remained relatively stable over the past decade.* As a percentage of all SAT takers, students scoring 650 or above on the SAT mathematics test increased from 7.9 percent in 1975 to 8.7 percent in 1984. (See p. 129.)
- *In 1982, high school graduates on the average took 2.2 years of science and 2.7 years of mathematics during their 4 years of high school.* Except for basic courses, such as biology, algebra I, and geometry, enrollment in science and mathematics courses was generally low. (See pp. 130-131.)
- *The 10th grade is the last time that most high school students in the U.S. are exposed to science.* Less than half of the juniors and only one-third of the seniors take a science course. Furthermore, there has been a substantial drop (54 percent of all students in grades 9-12 took science courses in 1948-49, compared with 44 percent in 1981-82) in the percentage of students enrolled in precollege science courses from the late 1940's to the early 1980's. (See p. 131.)
- *American high school students take substantially less coursework in science and mathematics than students in other highly developed countries such as Japan, West Germany, East Germany, and the Soviet Union.* American students receive only one-half to one-third the exposure to science as their counterparts in these countries. (See p. 133.)
- *In a recent survey of international mathematics, U.S. students scored well below the Japanese and slightly below the Canadian students in British Columbia.* By the end of the 12th grade, U.S. students in calculus classes, considered to be the best mathematics students, scored at only the mean performance of all senior high school mathematics students in other countries. Thus, it is clear that the overall U.S. high school student body is less skilled in mathematics. (See pp. 133-134.)
- *Several recent surveys point to shortages of qualified teachers in subject areas such as science and mathematics, although the extent of these shortages varies significantly according to survey methodology.* Surveys of headcounts of teacher vacancies show that serious shortages exist only in certain fields such as physics and chemistry, while surveys of state science supervisors and placement officers indicate that severe shortages of qualified teachers exist in most fields of science and mathematics. The differences may result because opinion surveys consider the qualification of teachers to teach in the subjects to which they are assigned. (See pp. 134-135.)
- *Graduate Record Examinations (GRE) scores of college graduates in science and mathematics who are planning careers in education (exclusive of those who intend to become administrators) are significantly below the aver-*

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age of science majors intending to major in the same or related fields in graduate school. **Also, the typical grade-point average of undergraduate degree recipients in science and mathematics who intend to major in education is well below that of students intending to major in the same or related fields. (See pp. 135-137.)**

In 1983, six nation-wide commissions including the National Science Board's Commission on Precollege Education in Mathematics, Science and Technology published reports recommending reforms for our educational system.[1] In each of the 50 states, one or more commissions on education have been appointed by public officials.

The conclusions of these bodies are similar: that there are serious problems in precollege science and mathematics education which threaten our economic future and national security and the ability of all citizens to function in a high-technology society. These reports point out that many students leave high school without adequate preparation in science and mathematics. Colleges are required to spend large amounts of scarce resources on remedial education in these subjects. The reports identify shortages of qualified teachers of science and mathematics, poor teacher preparation, inadequate teacher compensation, adverse working conditions, and low academic standards as roots of the problem.[2]

Because of renewed interest in precollege science and mathematics, it is especially important to study the present conditions to provide benchmarks for measuring changes. The National Science Board Commission firmly believes that "achieving its educational objectives requires monitoring of educational progress, and that such monitoring will itself increase the speed of change."[3] Accordingly, this chapter examines statistics on precollege science and mathematics education, including student achievement and aptitude, the courses students take, international comparisons, and the supply and demand of teachers and their qualifications.[4]

STUDENT ACHIEVEMENT

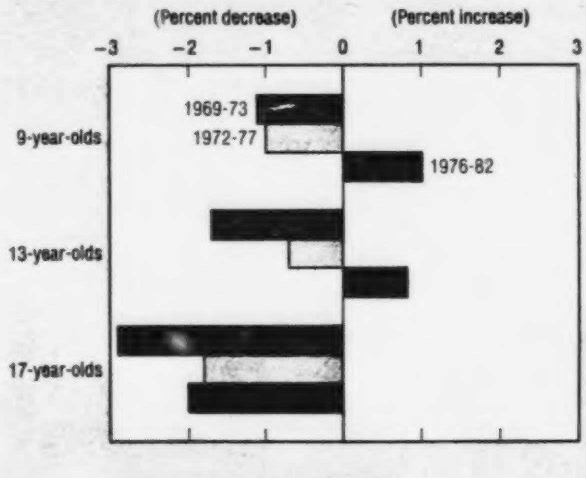
Recent studies assessing educational and training requirements for future U.S. production workers suggest that many prospective employees will not have the basic knowledge of science and mathematics required to perform their jobs effectively. Shortages of science and mathematics instructors at all levels impede the development of basic skills needed for careers in modern manufacturing.[5] Recent employer surveys, moreover, indicate widespread dissatisfaction with the quality of the education that high school graduates have received.[6]

Educational achievements of precollege students in the U.S. are most commonly derived from surveys such as the National Assessment of Educational Progress (NAEP). NAEP is designed to measure the knowledge of precollege students in a number of areas, including science and mathematics. NAEP conducted four science assessments during 1969-82 (the 1982 survey was a special supplement conducted for NSF by the University of Minnesota), and three mathematics assessments during 1973-82, based on national samples of students aged 9, 13, and 17.

In science, achievement trends showed overall declines during 1969-82 for all age groups. (See figure 6-1.) From 1969 to 1977, achievement scores in science declined 4.7

Figure 6-1

National trends[1] in achievement scores in science by age and year



[1] Change in average number of percent correct.

SOURCE: National Assessment of Educational Progress, Education Commission of the States, "Three National Assessments of Sciences," June 1978, and University of Minnesota, "Images of Science," June 1983.

Science Indicators—1985

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[1] See National Science Board (1983); National Commission on Excellence in Education (1983); Task Force on Education for Economic Growth (1983); College Entrance Examination Board (1983); Twentieth Century Fund Task Force on Federal Elementary and Secondary Education Policy (1983); and Boyer (1983).

[2] For information on efforts that are underway to improve the teaching and learning of science and mathematics by all students in elementary and secondary school and a comprehensive review of the data currently available to assess the condition of science and mathematics education in the Nation's schools, see Raizen and Jones (1985).

[3] See National Science Board (1983), p. 12.

[4] Original plans for this chapter included a section on student attitudes toward science and engineering, particularly in regard to achievement among minorities and women. Review of existing literature revealed, however, that inadequate national data exist to make valid inferences. To fill this gap, National Science Foundation will place priority on analyses related to this topic in the coming years.

[5] See Office of Technology Assessment (1984).

[6] See National Academy of Science (1984).

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percentage points for 17-year-olds, compared to about 2.4 percentage points for 13-year-olds, and just over 1 percentage point for 9-year-olds.

From 1977 to 1982, scores on achievement items administered to 9-year-olds improved 1.0 percentage point, representing the first overall positive change at any age level in the four science assessments. For 13-year-olds, there was a small improvement on achievement items, while scores of 17-year-olds declined by two additional percentage points. This decline was primarily due to significant declines of scores in earth sciences (-3.1 points), and integrated topics (-4.4 points). Biology continued to decline at about the same rate as the two previous assessments (-1.1 points). Physical science achievement remained more than 6 percentage points below 1969 levels.

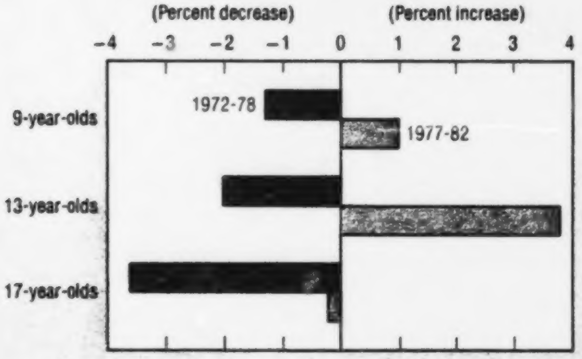
Whites at all age levels continued to outperform blacks, with the gap narrowing since 1977. Nine-year-old males scored only slightly higher than females, but 13-year-old males outperformed females with differences increasing to 3.4 points. For 17-year-olds, males outscored females by 3.3 points, less than their 1977 lead of 4.2 points.

The mathematics performance of 9-year-olds declined by 1.3 percent from 1972 to 1978, then increased by 1.0 percent from 1978 to 1982. (See figure 6-2.) Performance of 13-year-olds declined about 2 percentage points between the first two assessments and then improved almost 4 points between the second and third. Performance of 17-year-olds declined about 4 percentage points between the first and second assessments, then leveled off between the second and third.

Students' mathematical skills, knowledge, and understanding, and their application showed no significant changes for ages 9 and 17. However, improvement for 13-year-olds was shown in all four areas, mostly on the knowledge, skills, and understanding of exercises.

Figure 6-2

National trends[1] in achievement scores in mathematics by age and year



[1] Change in average number of percent correct.

SOURCE: National Assessment of Educational Progress, Education Commission of the States, "The Third National Mathematics Assessments: Results, Trends and Issues," April 1983.

Science Indicators—1985

At age 9, none of the racial groups (white, black, and Hispanics) showed a significant change in average performance in mathematics skills during 1973-82. However, black students and students in the lowest performance quartile improved on exercises assessing mathematical knowledge. At age 13, all of these groups showed significant gains in average performance. Students in schools with large minority enrollments showed gains at twice the national average. Black and Hispanic students gained close to 6 percentage points, compared to the national average of 4 points. At age 17, significant increases in average performance were registered by students attending schools with largely minority enrollments. That group improved 5 percentage points, while the national population of 17-year-olds made no gain at all.

A study based on SAT and NAEP data attempted to explain the consistent reductions during recent years in the size of average mathematics achievement score differences between white and black students.[7] Based on SAT quantitative test scores during 1976 to 1983 and NAEP mathematics assessments in 1973, 1978, and 1982, the study examined both school and individual background variables. The average SAT mathematics scores for white students declined by 9-scale points over the 8-year period, while average scores for black students increased by 15 scale points. In the NAEP assessments, at age 9 and 13, white children performed in 1982 neither better nor worse than in 1973, whereas blacks averaged 5 percent more correct answers in 1982. At age 17, over the same period, the white-black average difference declined by 2 percent. The study concluded that the best prediction of performance by far is the number of years taken of high school algebra and geometry. The study also concluded that the most effective way to improve mathematics achievement levels and to reduce further white-black achievement differences is to encourage further enrollment in mathematics courses in high school. Based on other studies, while recognizing that 17-year-olds' performance had stopped declining and 13-year-olds' performance had improved significantly since 1978, mathematics educators who reviewed the results of the three assessments nevertheless concluded that "—improvements have been largely in the knowledge, skills, and understanding exercises assessing things most easily taught and learned by rote. Concern [should be expressed] that performance on nonroutine problems and on problem solving in general continues to be unacceptably low."[8]

These findings point out that schools are doing a good job of teaching those mathematical topics that are relatively easy to teach, e.g., basic mathematical operations, such as those often found in textbooks. Within the context areas of geometry and measurement, students performed best and improved most on those items measuring recognition of shapes and measures. When they were asked to calculate areas and volumes, they were much less sucessful. Other analyses based on NAEP mathematics assessment data in 1982 suggest that students may not understand the underlying concepts of the problems they solve.

An investigation of student performance in the area of multi-step problem-solving and applications reveals that

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[7] See Jones (1984).

[8] See National Assessment of Educational Progress (1983).

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students at all three ages found multi-step word problems difficult. Likewise, nonroutine problem-solving skills, which call for some analysis of the problem and application of mathematical knowledge, were generally weak.

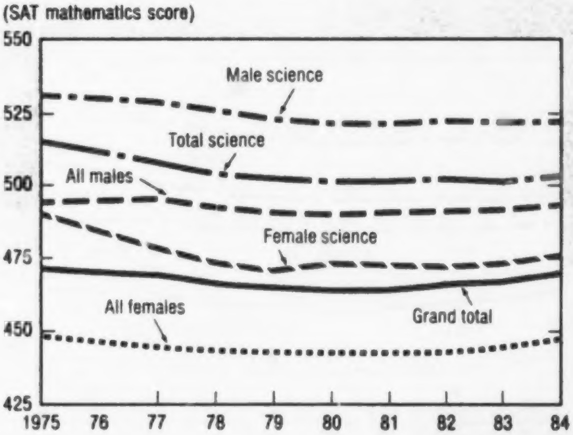
SCHOLASTIC APTITUDE

Students who intend to major in science or engineering (S/E) in college scored 59 composite points higher in 1984 on the verbal and mathematics portion of the Scholastic Aptitude Tests (SATs) than all other students taking these tests. (See figures 6-3 and 6-4.) In 1984, SAT takers intending to major in S/E disciplines had mean scores of 451 on the verbal test and 505 on the mathematics test, compared with 426 and 471 for the general population.[*]

The mean mathematics scores for students intending to major in science or engineering were approximately 33 points higher than all SAT takers, although the gap narrowed slightly from 1975 to 1984.

Figure 6-3

Mean SAT mathematics scores of prospective science and engineering majors and of all majors by gender



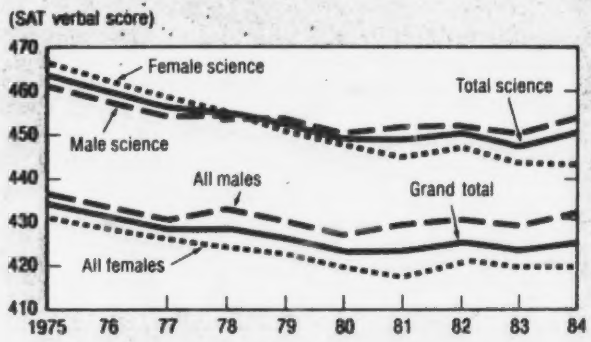
NOTE: Data are not available for 1976. SAT scores range from a minimum of 200 to a maximum of 800.

SOURCE: For all SAT takers: Educational Testing Service, National College-Bound Seniors (annual series); For science and engineering majors; Educational Testing Service, unpublished data.

Science Indicators—1985

Figure 6-4

Mean SAT verbal scores of prospective science and engineering majors and of all majors by gender



NOTE: Data are not available for 1976. SAT scores range from a minimum of 200 to a maximum of 800.

SOURCE: For all SAT takers: Educational Testing Service, National College-Bound Seniors (annual series); For science and engineering majors: Educational Testing Service, unpublished data.

Science Indicators—1985

The number of students intending to major in science or engineering increased steadily from 234,700 in 1975 to 288,800 in 1984, even though the total number of students taking the SAT declined after 1979, from approximately 820,000 to 780,000. The number of SAT takers represented about one-third of the entering freshman classes of college in both the fall of 1975 and the fall of 1984. Within S/E disciplines, dramatic shifts occurred. There was substantial growth in the number of SAT takers who intended to major in computer science (from 13,600 to 85,900), as well as sizable increases for those planning to major in engineering and in the social sciences. There were significant declines in mathematics and biological sciences, and a smaller decline in the physical sciences.

SAT scores for students intending to major in science or engineering declined during 1975 to 1984, approximately paralleling the declines for the total SAT population. The mean SAT math scores for students intending to major in S/E disciplines declined from 517 in 1975 to 503 in 1980-81, then rose slightly to 505 in 1984. SAT verbal scores were 464 in 1975, 450 in 1980-81, and 451 in 1984.

Mean SAT mathematics scores for women intending to major in science or engineering tended to be substantially lower than men's, with some exceptions. The mean scores for women in engineering (the highest of the means for women) tended to be 10 to 20 points higher than those for men, while those for women were substantially lower than the men's for physical sciences (where the means for men were the highest). Thus, the highest-scoring women tend to select engineering as a major, whereas the highest-scoring men select physical sciences.

As with men, the women who intend to enter science or engineering consistently earn mean scores in SAT mathematics that are higher than the mean scores for all SAT takers.

Similar results are shown on tests given by the American College Testing Program (ACT). Composite scores of four types of tests (English, mathematics, social studies,

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[*] All statistics summarized in this section are based on the SAT candidate population. This population is a subset of all students entering college each year, and of an even smaller self-selected subset of all high school seniors. Other data derived from the Student Descriptive Questionnaire, which most SAT takers complete voluntarily, are based on student self-reporting. While studies of the validity of self-reports have indicated that such data are sufficiently valid for most purposes, caution should be used in interpreting them.

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and natural science) and separate scores for mathematics and science are shown in appendix table 6-1, based on 10 percent samples of students who have taken the ACT tests between 1973 and 1984. Males have higher average scores than females in three of the four tests. In 1984, when all ACT scores increased, females made somewhat greater gains than males, but there was still a gap of 1.4 points in the composite scores (19.3 for males and 17.9 for females), a difference of 2.5 in mathematics, and 2.5 in natural sciences.

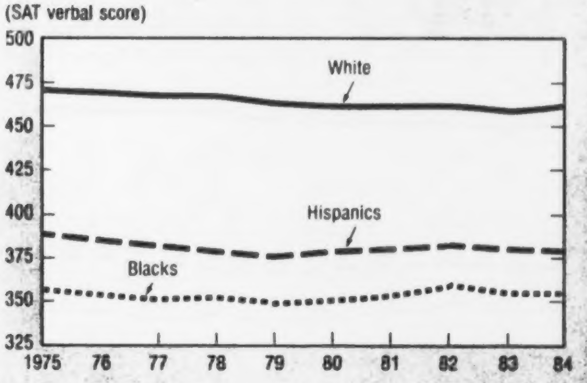
Black test takers indicating an intention to major in science or engineering steadily increased from 1975 to 1984; the number almost doubled but then fell off slightly in 1984. The pattern of numerical growth and decline across majors tended to resemble that of the total sample. Similarly, black students' mean SAT verbal scores followed the trends of those of the total S/E sample, except that the means averaged 112 points below white students' means. However, from 1975 to 1984, differences between the mean scores for blacks and whites narrowed, from 115 scale points to 110 scale points. (See figure 6-5.) For SAT mathematics scores, whites averaged 134 points above black students' means, but they too declined from a high of 143 in 1977 to 127 in 1984. (See figure 6-6.)

More black males intended to enter engineering than any other discipline, but by 1984 the number citing computer science increased nearly to the number citing engineering. Black women tended to choose computer sciences or the social sciences. The mean SAT verbal scores of black females were consistently slightly lower than those of black males, whereas the SAT mathematics scores of the black women tended to be about 30 points lower than those of the black men.

Hispanic students taking SAT tests and indicating an intention to major in science or engineering increased from 4,000 in 1975 to 10,000 in 1984. The number interested in engineering (the most popular field) tripled, and the number citing computer sciences increased five-fold. The SAT verbal means of Hispanic students tended to run about 80 points less than the means for white students, with no evidence of change in the size of the differences over time. The SAT mathematics scores of whites and Hispanics showed a similar difference.

Figure 6-5

Mean SAT verbal scores of all prospective science and engineering majors by ethnicity



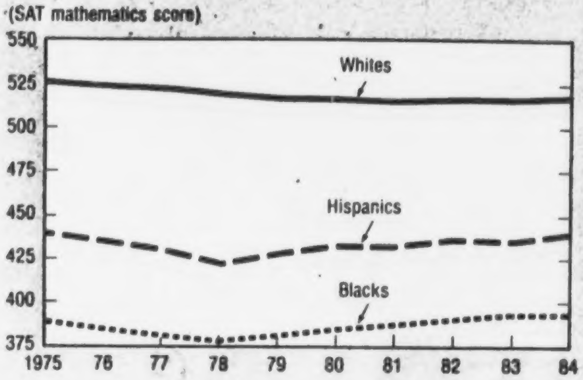
NOTE: Data are not available for 1976. SAT scores range from a minimum of 200 to a maximum of 800.

SOURCE: Educational Testing Service, unpublished data.

Science Indicators—1985

Figure 6-6

Mean SAT mathematics scores of all prospective science and engineering majors by ethnicity



NOTE: Data are not available for 1976. SAT scores range from a minimum of 200 to a maximum of 800.

SOURCE: Educational Testing Service, unpublished data.

Science Indicators—1985

In 1984, approximately 17 percent of all SAT takers intending to major in science or engineering reported that they expected to need help in college to improve their mathematics ability. A higher percentage of the students selecting earth, environmental, and marine sciences anticipated that help would be needed; the lowest percentage was in prospective physical science majors. A relatively high percentage of black students (32 percent) anticipated such a need, as opposed to about 16 percent of white students. The percent of female students anticipating a need for help was only slightly greater than for males.

A panel was formed in 1982 to seek possible explanations for the generally declining test performance of students.[10] It found that precollege school data from standardized test and national assessments point to better performance among the youngest students, but a continual decline in the upper grades. However, the patterns of change have become different over the past two decades. Through the 1960's, the greatest decline occurred in computational skills; during the 1970's and 1980's, in comprehension and analytical skills.

The panel attributed about half of the general decline in scores from 1960-1972 to changes in the composition of students taking the tests. As educational opportunity

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[10] See Austin and Garber (1982).

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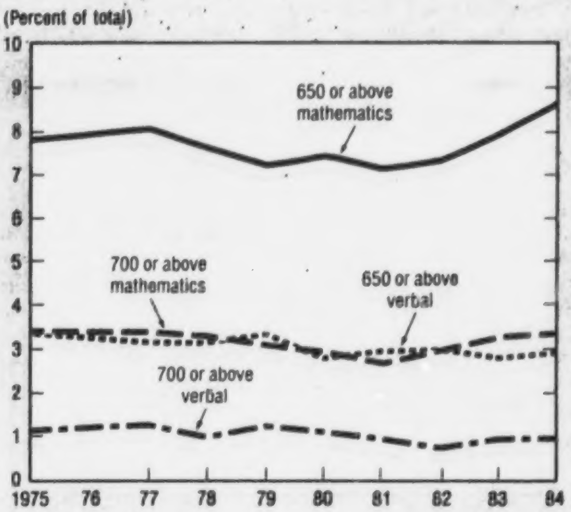
expanded in the U.S., increasing numbers of lower ability students began taking the tests. Other factors believed to have contributed to the decline in scores were diminishing standards in education, increased tolerance of absenteeism, grade inflation, automatic promotion, reduction of homework, and lower reading levels of textbooks. The panel also supported the proposition that most television programs detract from homework and compete with school. Lastly, most of the panel members thought that student motivation played a role in score declines; e.g., students now concentrate less on the tests since the opportunities for getting into college without them have widened.

Another recent study of changes in academic achievement of high school seniors between 1972-80 found that the major factor contributing to test score decline was a decreased emphasis on academic attainment in the educational process.[11] Relatively more seniors were enrolled in the general or vocational curricula in 1980 than in 1972, while fewer students were enrolled in the academic curriculum. Students in the academic curriculum decreased from 46 percent of all seniors in 1972 to 38 percent in 1980. Seniors in the general curriculum increased from 32 percent of the total in 1972 to 37 percent in 1980. The shift into the general curriculum was greater for males than females and occurred primarily among white students.

A related study showed that a significant number of students who were sophomores in 1980 and seniors in 1982 moved out of the general curriculum into the vocational curriculum during their last 2 years of high school.[12] In their sophomore year, 43 percent of the students who stayed in school were enrolled in the general curriculum and 19 percent in the vocational curriculum. By the senior year, 33 percent of the students reported being in the general curriculum and 27 percent in the vocational curriculum.

Figure 6-7

Percentage of prospective majors in science and engineering who scored 650, 700 or above on the SAT



NOTE: Data are not available for 1976. SAT scores range from a minimum of 200 to a maximum of 800.

SOURCE: Educational Testing Service, unpublished data.

Science Indicators—1985

TOP TEST SCORES

The quality of students with the best academic ability, as indicated by top test scores on the SAT verbal and mathematics tests, remained relatively stable from 1975 to 1984. However, based on the number of students taking advanced placement exams, there has been a relative shift of interest away from mathematics as a subject by the best students.

Students scoring 650 or above (of a possible top score of 800) on the SAT mathematics test increased from 7.9 percent of the total in 1975 to 8.7 percent in 1984. (See figure 6-7.) There has been a steady increase in the percentage of all SAT takers scoring 650 or above on the mathematics test since 1980; further, females scoring 650 or above on the mathematics test increased slightly from 3.7 percent of the total in 1981 to 5.0 percent in 1984. (See appendix table 6-2.) Students scoring 700 or above on the mathematics test declined slightly from 3.4 percent of the total in 1975 to 3.0 percent in 1984.

As indicated by the relative volume of test takers on Advanced Placement examinations, interest by some of the best students in biology, chemistry, and physics has remained much the same over the past decade, while interest in mathematics has declined more than any other subject. (See appendix table 6-3.) Advanced Placement (AP) courses and examinations are given at over 20 percent of American secondary schools to 15 to 20 percent of their college-bound students. Participants do college-level work and are generally high-achievers and highly motivated. Students' interest in taking AP courses is enhanced because many colleges and universities give advanced standing to those who score well.

Although the absolute number of students taking AP mathematics examinations more than doubled, the percentage of all AP students who took mathematics examinations declined from 20.3 percent in 1974 to 17.8 percent in 1983. Mathematics (calculus) dropped from the subject of second greatest interest in 1974 (English being first) to third in 1977 and thereafter. Biology, chemistry, and physics were in 4th, 6th, and 9th places in 1974 and in 1983.

UNDERGRADUATE STUDENT QUALITY

Another important indicator of the effectiveness of high schools is the quality of graduates who go on to college and major in science or engineering. In 1982 in a nationally representative survey of senior academic officials at 254 institutions with S/E programs, most (61 percent) believed that student quality had not changed significantly over the previous 5 years.

About one-fourth thought that the quality of their S/E students had improved and roughly one-sixth felt that they

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[11] See Educational Testing Service, December 1984.

[12] See Educational Testing Service, March 1985.

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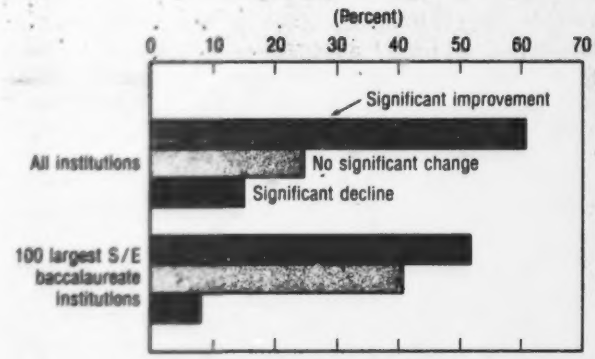
had declined significantly. (See figure 6-8.) When asked about shifts of their most able students away from S/E fields, the majority (53 percent) believed that no such shifts had occurred over the past 5 years. In fact, about two-fifths of the officials said that their most able majors were shifting into S/E fields—computer science (32 percent), engineering (18 percent), and the physical sciences (6 percent). Changes in student perceptions about employment opportunities after receiving their degrees was considered the dominant reason for their shifting into S/E fields.[13]

Figure 6-8

Perceptions of change in quality of S/E undergraduates: 1977-82



SOURCE: Frank J. Atelsek, *Student Quality in the Sciences and Engineering: Opinions of Senior Academic Officials*, Higher Educational Panel report no. 58 (Washington, DC: American Council on Education, February, 1984).

Science Indicators—1985

COURSES AND ENROLLMENT

Because the U.S. school system consists of 16,000 independent districts, each with mathematics and science programs of its own design or selection, it is difficult to generalize about student coursework. For example, an examination of course catalogs (as part of a national survey of high school students) found 47 different mathematics courses, 32 life science courses, 35 physical science courses, and 4 unified science courses.[14] Another study identified 135 different science courses, but found that most of the enrollment was confined to 8 or 9 of the traditional ones.[15]

Although course titles are diverse and content may be even more varied, numerous studies have shown that student achievement correlates strongly with the instructional time that students spend on a subject.[16] The relationship between mathematics achievement and coursework is especially close. In a special study based on analyses conducted by the Wisconsin Center for Educational Research in 1984, a direct relationship was found between the average achievement scores and the average number of years that students took Algebra 1, Algebra 2, or Geometry.[17] These analyses were based on national probability samples of seniors in 1980 and 1982 in the High School and Beyond survey. For both groups of seniors, the mean scores on mathematics tests for those students reporting no mathematics were about 22 points below those reporting five courses in mathematics. (See table 6-1.)

Data from a national longitudinal survey[18] conducted in 1982 reveal that high school graduates on the average took only 2.2 years of science and 2.7 years of mathematics during their 4 years of high school. Students in academic programs took more years of both science and mathematics than students in general or vocational programs. (See figure 6-9.)

Table 6-1. Average mathematics scores for 1980 and 1982 high school seniors by mathematic courses taken

	Mean standard score	
Mathematic courses taken	1980 seniors	1982 seniors
None	41	39
Algebra 1	44	44
Algebra 1, 2	46	46
Algebra 1, geometry	50	49
Algebra 1, 2, geometry	54	52
Algebra 1, 2, geometry, trigonometry, & calculus	63	62

SOURCE: Jones, L. V., "White-Black Achievement Differences", *American Psychologist*, vol. 39, no. 11 (November 1984).

Science Indicators—1985

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[13] See American Council on Education (1984).

[14] See National Center for Education Statistics (1984a).

[15] See Welch, Harris and Anderson (1985).

[16] See Borg (1981).

[17] See Jones (1984).

[18] See National Center for Education Statistics (1984a).

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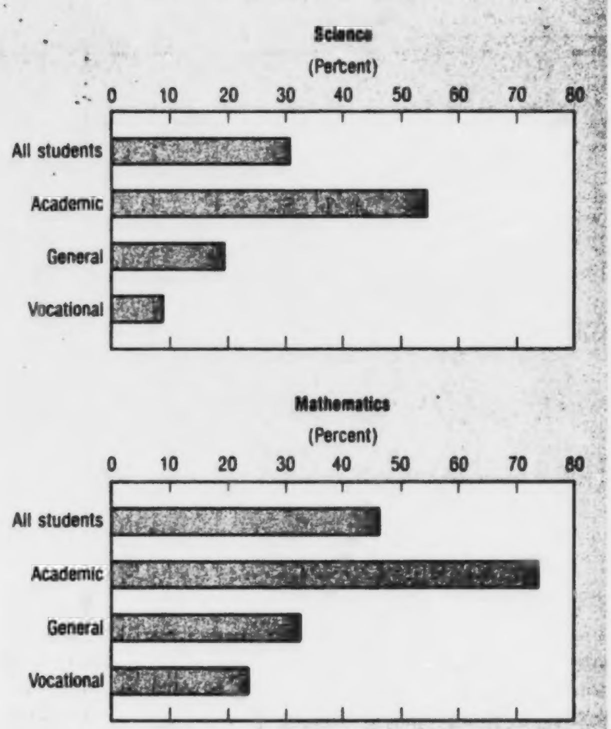
Figure 6-9

Percentage of 1982 high school graduates who took at least 3 years of mathematics and science, by type of program



SOUCRE: National Center for Educational Statistics, *Science and Mathematics in American High Schools: Results from the High Schools and Beyond Study*. (NCES 84-2116).

Science Indicators—1985

Except for basic courses (especially biology, in which 70 percent of the students were enrolled), enrollment in science courses was generally low. Other basic courses such as Chemistry 1 and Physics 1 each enrolled less than one-fourth of the students (24 and 11 percent, respectively). Only small percentages of students took advanced courses such as advanced chemistry (4 percent), advanced physics (1 percent), advanced biology (8 percent), and zoology (6 percent).

The same patterns were seen in mathematics courses. Algebra 1 had been completed by two-thirds of the students and geometry by 48 percent. But fewer than one-third had been enrolled in Algebra 2, compared with 8 percent in advanced algebra, 7 percent in trigonometry, 6 percent in calculus, 13 percent in other advanced mathematics courses, and only 1 percent in statistics.

During 1981-82, a special supplement to the National Assessment of Educational Progress in science was conducted, which included questions about science enrollments in junior and senior public and private high schools (grades 7-12).[19]

Overall, 90 percent of the students in grades 7-8 took a science course; however, in the ninth grade, only three-fourths of the students did. (See table 6-2 and appendix table 6-4.)

The most significant characteristic of high school science enrollment was the sharp decline in the upper grades. The 10th grade was the last exposure that most pupils have to science. In the 10th grade, 82 percent of all students were enrolled in science courses, but less than half the juniors and only a third of the 12th graders took any science courses. Slightly more than half (56 percent) of the students in grades 10 through 12 took any science classes.

Trend data on enrollment of students in all high school science courses are not available. However, a special analysis[20] was made of the number of students enrolled in eight common courses for selected years over a 32-year period. These eight courses include about three-fourths of the total science enrollment in grades 9 through 12. Though the data showed a slight upturn in the number of students enrolled in science in the last 5 years for which data were available (1976-77 to 1981-82), there was a significant decline from 60 percent in 1960-61 to 44 percent in 1976-77. (See figure 6-10.) This is still well below the figure of 54 percent of approximately three decades ago. The peak year 1960-61 probably reflects the great interest in science during the immediate post-Sputnik period.

Although many factors determine what courses students elect to take, one possible explanation of why students do not take more science and mathematics is that many tend to enroll in courses where good grades can be achieved with little, if any, homework. A recent study,[21] for example, showed that substantially higher grades are given in visual and performing arts (V&PA)[22] and in personal and social development (P&SD)[23] courses than in courses in any other instruction program category, making these subjects relatively attractive to many students. The percentage of A's in these two areas was about 2.5 times the percentage of A's in mathematics courses and more than twice those given in physical science courses; the percentage of D's and F's was only about one-third to one-half as great. V&PA and P&SD courses, which are nearly always electives, accounted for about 20 percent of all high school credits earned, compared with about 12 percent for mathematics and 4 percent for physical sciences.

Another important factor is geography, since there is considerable variation in science enrollment among various regions of the United States. In 1981-82, the Northeast was well above the other regions in the proportion of

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[19] See Hueftle, Rakow, and Welch (1983).

[20] See Welch, Harris and Anderson (1985). The eight courses are general science, biology, botany, zoology, physiology, earth science, chemistry, and physics. The study was based on surveys conducted by the National Center for Education Statistics of the numbers of students in grades 9-12 enrolled in the eight common courses for selected years and data reported by Welch of the percentage of grade 9-12 students in these eight courses for 1948-49, 1960-61, and 1972-73.

[21] See National Center for Education Statistics (1984b).

[22] Includes courses in crafts, dance, design, dramatic arts, film arts, fine arts, graphic arts technology, and music.

[23] Includes the following subcategories: basic skills, citizenship/civic activities, health-related activities, interpersonal skills, leisure and recreational activities, and personal awareness.

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Table 6-2. Science enrollments in junior and senior high schools by type of course: 1981-82

Type of courses	Junior high	Senior high	Junior high	Senior high
	Enrollments		Percent	
Total courses	10,151	9,623	100	100
Total science	8,691	5,365	86	56
General science	2,698	225	27	2
Life science	1,939	0	19	0
Biology	533	2,261	5	23
Physical science[1]	1,493	220	15	2
Chemistry	0	1,132	0	12
Physics	0	504	0	5
Earth sciences	1,459	118	14	1
Other sciences	569	905	6	9

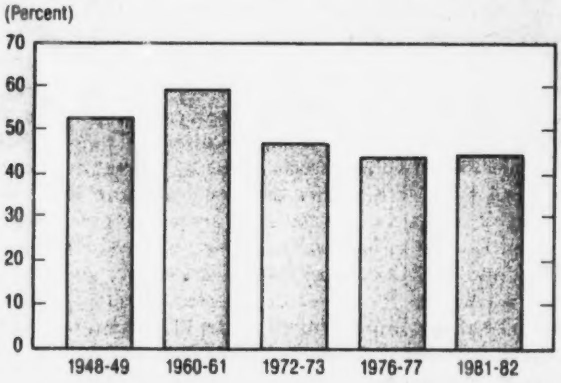
[1] Data are not available for physics and chemistry courses in junior high school.

See appendix table 6-4.

Science Indicators—1985

Figure 6-10

Enrollment in one or more of eight science courses as a percent of all enrollment, grades 9-12



SOURCE: University of Minnesota, unpublished data.

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students enrolled in science courses in both junior and senior high school. In the Northeast, 97 percent of junior high students took science courses compared with two-thirds in senior high school. The West lagged behind other regions in the junior high school years with only 72 percent science enrollment. In high schools in Southeastern states, only 47 percent of all students were enrolled in science courses. Science course enrollment of 12th graders was especially low in the Southeastern and Western states. (See appendix table 6-5.)

INTERNATIONAL COMPARISONS

Data on international comparisons of science education systems must be interpreted with caution because the structure and goals of these systems vary widely among nations. The social and political milieu, natural resources, and economic conditions have substantial impacts on educational systems. Also, relative emphasis on science and technology education in foreign countries, particularly communist countries, does not mean that the knowledge acquired by comparatively large segments of the population will be translated into the betterment of citizens. Nevertheless, at a stage when U.S. education policies are being reexamined, it is important to place our system within a global context.

A recent study of Japan, China, East Germany, West Germany, and the Soviet Union found that instruction in mathematics and the sciences in these five countries is more closely linked to the requirements of modern industrial society than is the case in the United States.[24] Particularly in the communist countries, more emphasis has been placed on training students to be productive members of the labor force and to develop skills that are relevant to technology; thus, knowledge of science and technology and its application in industry is considered essential for understanding and living in the modern world.

In the United States, the current practice is for public school students to take one science subject for one academic year and then move to another discipline the following year. In contrast, the preferred approach in these other five countries is the parallel teaching of an array of disciplines over a period of years.

Although country-by-country comparisons are difficult to make, it appears that American students spend only

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[24] See American Association for the Advancement of the Sciences. (1985) and Hurd (1982).

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one-half to one-third as much time learning science as their counterparts in the USSR and the other four countries. This statistic takes into account the days of instruction per year (about 180 in the United States versus 210 to 220 in the other five countries), attendance patterns, length of school day and week, fraction of total school time allotted to science, and amount of homework assigned.

Science and mathematics teachers in these other countries receive more special training than their American counterparts. They are trained in specially designed programs in a university, pedagogical institute, normal school, or teachers' college. Each of the five countries has provisions for a continuing program of in-service education.

Comparisons with programs in other countries[25] show that in many European countries, biology, physics and mathematics are taught concurrently for the last 2 or 3 years of secondary school, while in the U.S., one-half of all high school graduates have taken no math or science beyond 10th grade. In the Soviet Union and Eastern European nations, an attempt is made to expose all students to mathematics and science every year for 10 years, including 5 years of physics, 5.5 years of biology, 4 years of chemistry, 1 year of astronomy, 2 years of calculus, 7 years of algebra, and 10 years of geometry. In the United States, fewer than one-third of all school districts require more than one year of science or mathematics in grades 9 through 12. In the People's Republic of China, which has the largest school system in the world, all students take elementary science, chemistry, physics, and biology.

Another comparative analysis of the U.S. and Soviet Union's precollege systems found that perhaps the greatest contrasts are the Soviet's emphasis on science and mathematics and the grades in which those courses are introduced.[26]

In the Soviet Union, mathematics is introduced in 1st grade, biology in 5th grade, physics in 6th grade, and chemistry in 7th grade. At the terminal point in the "incomplete secondary training" (grades five through eight), all students have had 8 years of exposure to mathematics, 3 years to physics, and 2 to chemistry.

In 1981-82, students and teachers in a national sample of over 500 classrooms in the U.S. joined their counterparts around the world in the second international study of school mathematics in two dozen countries.[27] The first study was conducted in 1964.

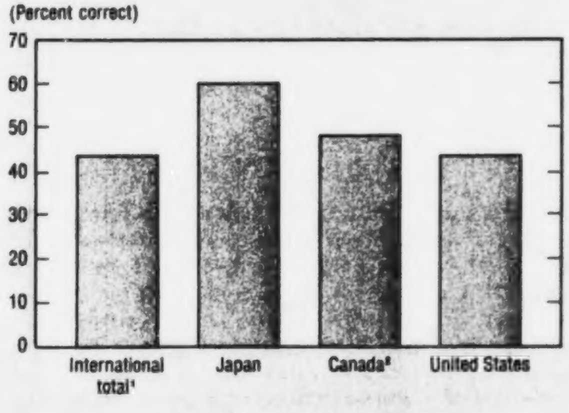
The 1981-82 study was targeted at 13-year-olds (eighth grade in the U.S.) and at college preparatory mathematics students who had taken at least 2 years of algebra and 1 year of geometry by the end of the final year of secondary school (twelfth grade in the United States). Two class types were surveyed and analyzed separately for the twelfth grade: precalculus and calculus. To date, individual country data are available for 1982 for the United States, Japan, and Canada (British Columbia); data are also available for 1964 and 1982 for the United States and Japan. In addition, composite international comparisons are available for 20 countries at the eighth-grade level and for 15 countries at the twelfth-grade level.

In the United States, the average number of hours per year provided for eighth grade mathematics instruction is 145. This is comparable to the amount of time devoted to mathematics instruction at this grade level in the vast majority of countries in the study. By the end of the 8th grade, U.S. students are at the international average of achievement in arithmetic and algebra, but well below the Japanese in all mathematics subjects. (See figure 6-11 and appendix table 6-6.) The U.S. students are slightly below the students in British Columbia in mathematics achievement as well. Between 1964 and 1982, the patterns of change in mathematics achievement scores for eighth graders were similar for both the U.S. and Japan. Both countries experienced a modest overall decline in mathematics achievement, including a decline in scores on arithmetic test items.

By the end of the 12th grade, the achievement of the Advanced Placement calculus classes, which enroll the Nation's best mathematics students, is at or near the average achievement of the groups of senior secondary school college-preparatory mathematics students in other countries. (See figure 6-12.) That is, the achievement of our best mathematics students (i.e., those taking college preparatory courses at grade 12) is only equivalent to the mean performance of all senior high school mathematics students in other countries. The average Japanese student in the 12th grade achieved scores that were substantially above our best students in all mathematics subjects tested. The U.S. pre-calculus students (approximately the remaining four-fifths of the 12th grade college-preparatory mathematics students) achieve at a level which is substantially below the international mean scores for all countries in the study, and in some cases are ranked with the lower one-fourth internationally. (See appendix table 6-7). For 12th graders, the patterns of change during 1964-82 are much more favorable

Figure 6-11

Algebra test scores at end of eighth grade, for selected countries: 1982



[1] This is the international average for 18 participating countries. For specific countries participating see Appendix table 6-6.

[2] Data are for British Columbia.

NOTE: Tests were administered to all students taking eighth grade mathematics.

See appendix table 6-6.

Science Indicators—1985

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[25] For example, see Gardner and Yager (1983).

[26] See Ailes and Rushing (1982).

[27] See International Association for the Evaluation of Educational Achievement (1985).

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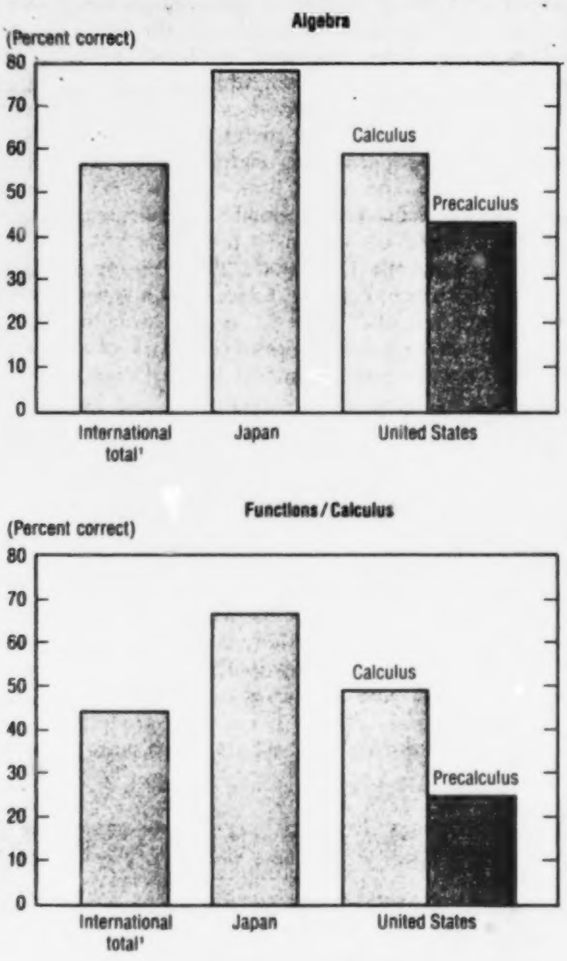
Figure 6-12

Mathematics test scores at the end of secondary school, for selected countries: 1982



¹This is the international average for 13 participating countries.

NOTE: These tests were taken by students in college-preparatory mathematic classes in the final year of secondary school, and are therefore a measure of content and effectiveness. The results may represent differing proportions of the total school population or age cohorts.

See appendix table 6-7. Science Indicators—1985

for the Japanese than for U.S. students. In total, achievement scores for students studying college preparatory mathematics increased about 11 percent for the Japanese, compared with 6 percent for the U.S. students.

A recent study of three cities in Japan, Taiwan, and the United States found that Americans lag even in the early grades.[28] In standard mathematics tests administered in the study, the Taiwanese students registered the best scores in the first grade and Japanese in the fifth grade, with American children third at both grades. American first graders accounted for only 15 percent of the top scorers in the mathematics tests. Among fifth graders, only one American student achieved a superior score, while the bottom group included 67 American students. All of the 20 American fifth-grade classrooms had lower average scores than the worst-performing Japanese classroom.

One explanation offered for the low mathematics achievement of these American elementary school children is that they spend less time in school, and of the time they do spend in school, a smaller proportion is devoted to mathematics than in the other two countries. For example, teachers in the United States spend a much lower proportion of time on mathematics instruction than on language arts, which includes reading, spelling, and writing.

TEACHERS OF SCIENCE AND MATHEMATICS

Many recent studies have pointed to a shortage of qualified teachers of science and mathematics in the public schools. Reports of national commissions argue that a shortage of qualified teachers has adversely affected the quality of education. Whether survey findings show that the shortage is critical or moderate, however, depends on the methods used. For example, head counts of the number of unfilled teaching positions indicate that the shortages are moderate and exist only in certain areas such as physics, chemistry, and mathematics. Conversely, opinion surveys of university placement officers or state science supervisors show that the shortages are severe. Differences may result because in opinion surveys, respondents can estimate the extent to which unqualified teachers are being utilized.

Both types of surveys suffer from defects. Head counts suffer because some school districts simply eliminate courses that were previously taught because teacher vacancies cannot be filled or vacancies are filled with unqualified teachers. The important question of quality is either not addressed or is estimated by using proxies for quality such as teacher certification.

The results of opinion surveys are difficult to interpret because opinions cannot be translated into actual numbers of teachers represented in the shortages. In addition, individual perceptions are lacking in uniform definition and interpretation, i.e., we do not know whether a shortage is defined by the respondent as being classrooms without teachers, or by empty classrooms plus those with teachers who are not fully qualified in the subject area they teach.

In 1984, the National Center for Education Statistics surveyed school administrators for information on budgeted positions, present teachers (both those newly hired and those continuing), and their certification status.[29] Preliminary results do not indicate serious shortages of science and mathematics teachers. (See appendix table 6-8.) Except for physics, where shortages were 4.5 teachers per thousand, and to a lesser extent chemistry, with 1.9 teachers per thousand, shortages in the sciences and mathematics were about the same as the overall average of 1.5 per thousand for all secondary teachers. (See table 6-3).

Relatively large numbers of teachers were not certified to teach in the fields to which they were assigned. The

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[28] See Stevenson (1983).

[29] See National Center for Education Statistics (1984c).

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Table 6-3. Shortages and field certification status of precollege teachers, by level and field: 1984

Fields	Shortage per 1000 teachers	Non-certified as percent of all in field
	All levels	
All fields	1.6	3.5
All science fields	1.7	4.1
Biology	1.7	3.8
Chemistry	1.9	4.1
Physics	4.5	5.6
Other sciences	1.4	4.0
Mathematics	1.8	4.1
	Secondary	
All fields	1.5	3.3
All science fields	1.4	4.1
Biology	1.7	3.8
Chemistry	1.9	4.1
Physics	4.5	5.6
Other sciences	0.8	4.0
Mathematics	1.4	4.1
	Elementary	
All fields	1.6	3.6
General science	3.9	4.0
Mathematics	4.1	4.2

See appendix table 6-8.

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proportion of non-certified teachers in science and mathematics was higher than in other teaching fields.[30]

Only 3.3 percent of all secondary teachers lacked field certification for their teaching, compared with 4.1 percent of all science and mathematics teachers. In physics, nearly 6 percent of teachers were not field certified.

In a national survey in the fall of 1980, and again in 1981 and 1982, most of the 50 state science supervisors reported worsening shortages in mathematics and physical sciences in their states in each succeeding year.[31] (See table 6-4.)

By the 1982-83 school year, only three states reported an adequate supply of mathematics teachers, four of physics teachers, and five of chemistry teachers. By contrast, 41 had enough biology teachers and 33 had enough general science teachers.

Another survey conducted in 1983 found that only five states had no shortages, while the number of states indicating a shortage in particular fields ranged from 35 in mathematics to one in biology.[32] Five states indicating no shortage of mathematics teachers in 1983 said that they expected a shortage the following year, as did three states for science teachers.

A continuing survey of placement directors found near-critical shortages of teachers in mathematics, physics, chemistry and two computer fields in 1984.[33]

Not only are the qualifications of science and mathematics teachers in question, the number of new teachers has been declining. As shown in figure 6-13, a survey of 600 colleges and universities found a 77 percent decline between 1971 and 1980 in the number of college mathematics graduates prepared to teach in secondary schools. There was also a 65 percent decline in the number of college science graduates. Additionally, the fraction of those graduates who enter teaching has declined, so the effect of these trends together was a 68 percent drop in newly employed science teachers and an 80 percent drop in newly employed mathematics teachers over the decade.

While fewer college graduates are choosing teaching as a career, the academic credentials of those entering the teaching profession also appears to be relatively low. In 1982, SAT scores of high school graduates who intended to major in education were 32 points below the national average on the verbal test and 48 points below on the mathematic test.[34]

SAT scores for students planning teaching careers are not available separately for proposed teaching fields; thus, we do not know whether scores of those planning to teach science or mathematics are significantly lower than those of other students. But Graduate Record Examination (GRE)

Table 6-4. States reporting a shortage of science and mathematics teachers

Subject	Critical shortage		Shortage	
	1980-81	1982-83	1980-81	1982-83
Physics	21	27	22	15
Mathematics	16	21	19	24
Chemistry	10	16	25	30

SOURCE: Howe and Gerlovich, "National Study of Estimated Supply and Demand of Secondary Science and Mathematics Teachers", Working document, Iowa State University, Ames, Iowa, 1982, and Howe, T.G. and I.A. Gerlovich, "Where the Jobs Are", *The Science Teacher*, March, 1983.

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[30] Although there is no unanimity among the states regarding the requirements for certification, "general certification" usually indicates that the individual has successfully completed such pedogogical courses as are required by the individual states, and has served an apprenticeship of varying length as a student teacher. "Field certification," on the other hand, also requires the completion of certain courses or credit hours in the subject field. The number of college credits required for certification in the relevant discipline is specified by states and varies substantially among the states. Furthermore, the sequence and content of required courses often depends on policies of individual institutions of higher education. There is also disagreement about the proper mix of disciplinary and pedagogical courses as determinants of effective teaching. For a detailed analysis of the issues surrounding data on the supply, demand, and quality of precollege science and mathematics teachers, see Committee on National Statistics (1985).

[31] See Howe and Gerlovich (1982) and Howe and Gerlovich (1983).

[32] See Education Commission of the States (1983).

[33] See Akin (1980) and Akin (1984).

[34] See Carnegie Foundation for the Advancement of Teaching (1983).

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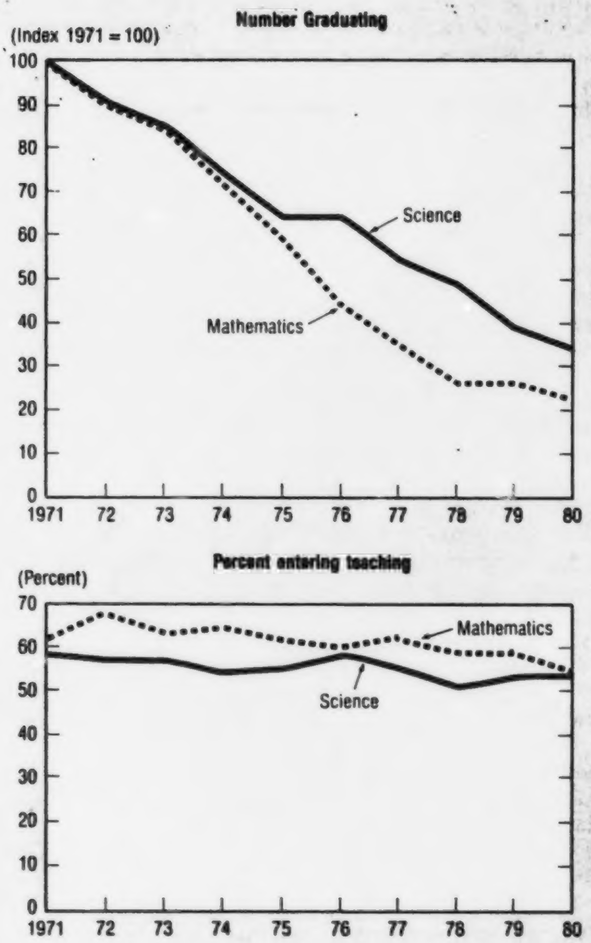
Figure 6-13

Supply of new science and mathematics teachers



SOURCE: National Science Teachers Association, "Survey of College and University Placement Officers," 1982.

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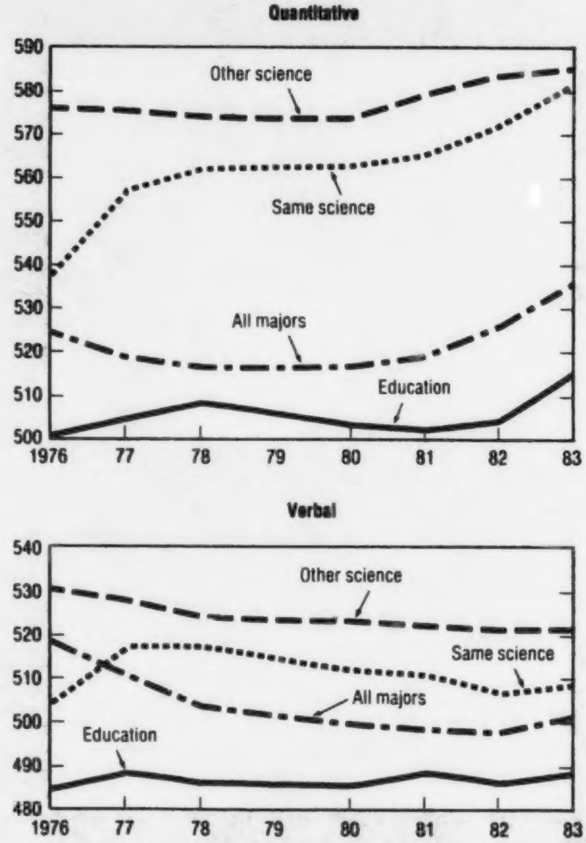
scores for college graduates in science and mathematics who plan to enter graduate studies in education and other areas do indicate differences. Among U.S. citizens, the average GRE scores for those having an undergraduate degree in science or mathematics is lowest among students planning to major in education (excluding administration) at the graduate level. (See figure 6-14.) Undergraduates with a degree in science or mathematics who planned to major in education at the graduate level scored below the mean of all GRE examinees and well below the average of undergraduate S/E majors who planned to also major in the same or related field in graduate school.

Mean undergraduate self-reported grade-point-averages (GPA) for U.S. citizens also indicate that students with the best subject-matter knowledge are not going into education at the graduate level. Undergraduates with science and mathematics degrees who intend to major in education at the graduate level had GPA's that were lower than the national GPA average and also below the average for those bachelor's degree recipients who intended to continue in science studies at the graduate level. (See figure 6-15.)

Although test-takers planning to enter the teaching profession generally score lower than others, it appears that the ability of prospective teachers has not been declining in three specialty areas related to science and mathematics (chemistry, physics, and general science) and may have actually increased. (See figure 6-16.) These conclusions are based on mean scores on the National Teacher Examination (NTE) during 1980-84, which was administered to approximately 25,000 prospective teachers in eight states and New York City and Chicago. The specialty areas measure understanding of the content and methods applicable

Figure 6-14

Graduate Record Examination scores by intended major in graduate school[1]



[1] U.S. citizens only. Excludes education administration.

NOTE: Data not available for 1979. GRE scores range from a minimum of 400 to a maximum of 700.

SOURCE: Educational Testing Service, unpublished data.

Science Indicators—1985

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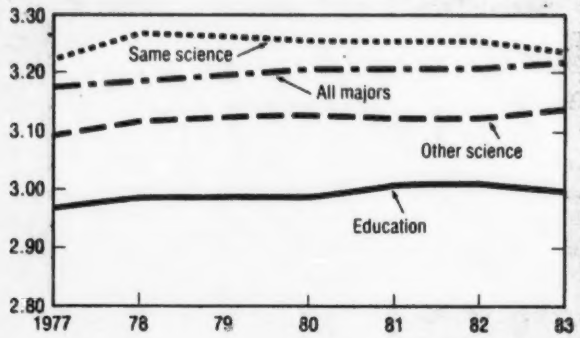
Figure 6-15

Mean overall GPA by intended major[1] in graduate school



[1]U.S. citizens only.

NOTE: Data not available for 1979.

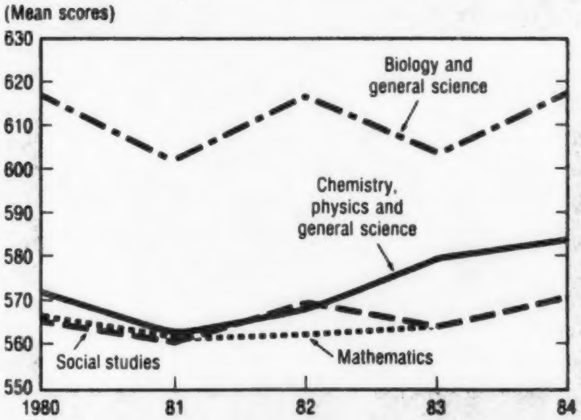
SOURCE: Educational Testing Service, unpublished data.

Science Indicators—1985

to the separate subject areas. The major qualifications on the interpretation of the NTE are the limited number of states requiring the test in all of the years and the unknown number of persons taking the test who actually went on to enter the teaching profession.

Figure 6-16

Mean scores on the National Teachers Examination in four specialty areas



NOTE: Each specialty area test has its own scale that is not necessarily equivalent to any other area test scale.

SOURCE: Educational Testing Service, unpublished data.

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A recent report[35] referred to the "structural problem of the teaching profession", listing a number of factors contributing to the present adverse situation. Among these factors were: demographic trends creating supply and demand imbalances for teachers; women and minorities who formerly went into teaching now choosing other professions offering greater financial rewards; low teachers' salaries; and dwindling non-pecuniary awards such as lack of input into professional decisionmaking, restrictive bureaucratic controls, and inadequate administrative support.

OVERVIEW

In the last 2 years, a number of reports have been issued, including that of the National Science Board's Commission on Precollege Education in Mathematics, Science and Technology, that question the overall quality of precollege education in the United States. These reports have received much publicity and have raised public awareness of national issues surrounding elementary and secondary education. A common theme of these reports is that the achievement levels of our Nation's youth are insufficient in science and mathematics to meet present and future economic, technological, and military demands, and that there is a national need to ensure scientific and technical literacy for all students. In support of this position, a recent study by the National Academy of Sciences found that high school graduates who proceed directly to the workplace need very nearly the same education in the core competencies as those going on to college. Out of the national debate has grown a consensus that all students must have a solid basis of knowledge about science and mathematics to function in the society of the next century.

National assessments of science and mathematics over the last decade show significant and continual declines for achievement of 17-year olds. These declines in mathematics are primarily in student abilities to conceptualize and solve multi-step problems rather than mathematical computation. Scores on college entrance examinations (SATs and ACTs) have declined over two decades for the general population and for students who intend to major in science and engineering in college. Women's mean SAT mathematics scores tend to be substantially lower than men's. Blacks and Hispanics also score much lower than whites, but the differences have been declining. And the academic credentials of persons entering the teaching profession appear to be relatively low. The average GRE scores for college degree recipients in science or mathematics is lowest among those planning to major in education. The grade point average for undergraduates who intend to major in education in graduate school is below the national average.

Yet, there are some positive signs. There was an increase in the percentage of students with high scores (650 or above) on the SAT mathematics test from 1975 to 1984 and the number has been rising for 3 years. National assessment results show that steady advances have been made by 9-year-old elementary school children and particularly by young minority students in areas of mathematics computation. Recent mathematics achievements scores have

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[35]See Darling-Hammond (1984).

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risen significantly for 13-year-olds. SAT scores began to rise in 1984 after a steady decline over two decades.

Perhaps the most encouraging sign is that local state school administrators are beginning to respond to the problem. Nearly every state has launched programs to improve science and mathematics in several areas, including: upgrading course requirements and offerings, improving the content and structure of current offerings, enhancing teacher qualifications and training, and improving the subject matter knowledge of teachers in areas they are certified to teach.

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Chapter 7

Public Attitudes Toward Science and Technology

Public Attitudes Toward Science and Technology

HIGHLIGHTS

- *Public has high level of interest in science and technology, but low level of knowledge.* Almost half of the American public report a high level of interest in issues concering science and technology. In 1983, 48 percent of the adults surveyed said they were very interested in issues concering new scientific discoveries and 44 percent were very interested in issues involving the use of new inventions and technologies. (See p. 143.)

- In contrast to interest, significantly fewer Americans feel well informed about public policy issues involving science and technology. In 1983, only 14 percent of the public classified themselves as very well informed about issues concerning new scientific discoveries or the use of new inventions and technologies. About 12 percent of college students consider themselves to be very well informed about science and technology issues. (See pp. 144-145.)

- *Public confidence in scientists.* The public expresses a high level of confidence in the scientific community. Out of 12 major American institutions, only the medical community receives a higher level of confidence, and the gap has been narrowing since 1973. (See p. 152.)

- *Public optimistic about future accomplishments of science and technology.* Looking to the future, the public holds high expectations for scientific and technological solutions to many important problems. In 1983, a majority thought it was "very likely" that in the next 25 years scientists and engineers would find a cure for the common forms of cancer. The public was not as optimistic about finding a safe way to dispose of nuclear waste. (See pp. 151-152.)

- *Public sees both benefits and dangers in science and technology.* A substantial majority of Americans believe that science makes their lives healthier and easier. In 1983, 88 percent of American adults subscribed to the notion that the future prosperity of the United States depended on "more and better technology." Six out of 10 Americans agreed that "most of the economic and social problems we face today" will eventually be solved by technology. In 1985, slightly less than 60 percent of American adults expressed the view that overall, science and technology have caused more good than harm. (See pp. 146,152.)

- At the same time, there is wide recognition that science and technology offer potential dangers. In 1983, three out of four Americans were concerned that through the development of biological, chemical, and nuclear weapons "science and technology may end up destroying the human race." (See p. 146.)

- Despite this awareness of potential dangers, survey results from 1979 and 1983 indicated that, with the exception of research involving the creation of new life forms, most Americans are opposed to placing restrictions on the kinds of studies that scientists and engineers may undertake. (See pp. 152-153.)

- *Public ambivalent about effects of science and technology on them.* The public appears to be able to differentiate among various technologies in terms of their likely effect on society. In 1983, 88 percent of Americans believed that computers will make the quality of their lives better. In contrast, only 48 percent of adults thought that nuclear power would have a positive effect on the quality of their lives. (See pp. 147-148.)

- The public is ambivalent about the impact of science and technology on the economy and employment. From 1983 to 1985, about equal numbers believed that science and technology lead to more employment and that they lead to less employment. A 1983 study found that 74 percent of adults agreed that factory automation was necessary to make American products competitive in international markets, and 71 percent agreed that factory automation will cause substantial unemployment. (See pp. 148-149.)

- *Public attentiveness toward science and technology.* In 1983, those citizens who reported a high level of interest in science or technology issues, felt well informed about those issues, and indicated a regular pattern of relevant information consumption (the "attentive public" for science and technology policy) made up approximately a quarter of American adults, an increase of four percentage points from comparable measures taken in 1979 and 1981. (See pp. 145-146.)

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Since science and technology have a continuing and expanding influence on the lives of the American people, this chapter assesses the public's perception of that influence. The citizen in a modern industrial society faces a wide array of complex public policy controversies. Science and technology compete for attention with other public policy areas. It is important to know what proportion of the public elects to follow science and technology policy matters, as well as the composition and attitudes of this segment of the public.

The expanding scope and impacts of science and technology have brought renewed attention to the possibility of governmental regulation of scientific research. To date, most governmental regulation has focused on the application of selected technologies. However, in areas such as the use of human subjects in research, experimentation with recombinant DNA, and the use of nuclear materials, Federal policies have been established that relate directly to both basic and applied research. The judicious use of this regulatory power requires a public that is knowledgeable about the benefits and risks of scientific research and technological development.

Further, it is the public who experience the impact of new technologies and may have to adjust their lives to accommodate changes in pace and lifestyle. Many examples, such as the automobile, radio, television, nuclear weapons, vaccines for polio and measles, and—more recently—home computers, are well known. It is important to understand the public's reaction to new technologies and to scientific research, which usually affects society more indirectly. This chapter explores the levels of public interest in and knowledge about science and technology, and the relationship between high levels of interest and knowledge and substantive policy attitudes.

INTEREST IN SCIENCE AND TECHNOLOGY

According to recent public opinion surveys,[1] the proportion of American adults with a high level of interest[2] in issues involving science and technology has increased markedly over the last several years. In 1983, nearly half of American adults reported that they were "very interested" in issues about new scientific discoveries or new inventions and technologies, considerably more than had such interest in 1979 and 1981.[3] (See table 7-1.)

Given the strong emphasis on "high tech" in our political dialogue, advertising, and educational system, this pattern of increasing public interest in issues involving science and technology should not be surprising.

Among the issue areas listed in the table, the level of interest in science and technology is exceeded only by public interest in economic issues and business conditions, which may be viewed as the traditional core political issues. The sharp increase in public interest in economic issues in 1981 and 1983 appears to reflect the level of conflict within the Congress and the Administration over the issues of inflation, unemployment, economic growth, tax reductions, and Social Security.

The effect of the changing national agenda can also be seen in the proportion of adults expressing a high level of interest in energy policy issues and space exploration. From the oil embargo of 1973 through the early 1980's, the supply and price of energy was a topic of national concern and of extensive Presidential and Congressional activity. The accident at Three Mile Island raised concern about the safety of nuclear power plants. In 1979 and 1981, about half of the American people surveyed reported a high level of interest in energy policy matters. By 1983, the immediacy of the energy problem, the frequency of media coverage of energy issues, and the proportion of Americans reporting a high level of interest in energy-related issues had all declined. (See table 7-1.)

In contrast to the nuclear power controversy, the American program of space exploration has not been the object of comparable organized opposition, and its achievements in the shuttle program and related efforts have received substantial public exposure via television and the press. Slightly more Americans reported a high level of interest in space exploration in 1983 than in 1981. Interest in space exploration is now on a par with public interest in foreign policy.

In 1979 and 1981, Americans who had college degrees were clearly more interested in science and technology than were other Americans. This was true for both sexes and all age groups (See appendix table 7-1.) However, the gap has been narrowing considerably. One result is that in 1983 no significant differences were found between those in the 17-34 age group who had college degrees and those who did not, with respect to their level of interest in science and technology. When new issues emerge on the national agenda, they are often first noticed and followed by better-educated citizens. The longer a set of issues is prominent in the news, the more likely it is to attract the attention of less well educated citizens. This pattern is particularly relevant to issues involving science and technology.

Young people show especially high levels of interest in science and technology. In 1983, undergraduate college students in a national study[4] were more interested in new scientific discoveries than in any other issue included in the study. (See table 7-1.) The second highest level of interest concerned the use of new inventions and technologies. On the other hand, the levels of interest in science and technology were not greater for students at the higher grades than for those in lower grades. Young people aged 18-25 who had never attended college seem to have similarly high levels of interest in science and technology.[5] Hence, it appears that this younger age group itself is especially interested in science and technology, regardless of college attendance.

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[1] The selection of samples from populations and the measurement of attitudes are grounded in modern social science theory. While the literature is clear that non-systematic sampling procedures or biased wording can produce erroneous results, all of the data reported in this chapter were collected by respected national survey organizations, often located in universities. For a comprehensive review of current survey research methods, see Rossi, Wright, and Anderson (1983).

[2] The method used to assess levels of interest was validated in an earlier study. See Miller, Prewitt, Pearson (1980).

[3] Throughout this chapter, only differences that are statistically significant at the .05 level will be discussed. For the sake of simplicity, exact significance levels will not be reported.

[4] 1983 College Youth Study (Simmons Market Research Bureau and the Public Opinion Laboratory at Northern Illinois University, private communication).

[5] Miller (1985). This result is based on a small sample, however.

Table 7-1. Public interest in selected policy issues: 1979-83

	All adults			College
Percent "very interested" in...	1979	1981	1983	1983
Economic issues and business conditions	35	54	57	33
New scientific discoveries	36	38	48	42
Use of new inventions and technologies	33	34	44	38
Energy policy	48	50	40	27
International and foreign policy	22	36	30	24
Space exploration	NA	26	29	33
N =	1,635	3,195	1,630	2,011

"There are a lot of issues in the world today and it is hard to keep up with every area. I am going to read a short list of issues and for each one—as I read it—I would like for you to tell me if you are very interested, moderately interested, or not at all interested in that particular issue."

SOURCES: Miller, Prewitt, Pearson (1980), Miller (1982, 1983c, 1984).

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KNOWLEDGE ABOUT SCIENCE AND TECHNOLOGY

It is important to examine the proportion of the public that thinks of itself as being well informed about issues involving science and technology. Previous analyses[6] have demonstrated that the subjective feeling that a person is reasonably informed about an issue area is strongly and positively associated with public participation in regard to that issue. Persons who think they are well informed are more likely to write a legislator or an agency about an issue, contribute to interest groups concerned with an issue, or take other actions intended to influence the policy formulation process. This subjective report of a respondent about how well informed he or she may feel is more relevant to learning about probable participation in the formulation of public policy than an objective test of scientific or technological knowledge would be.[7]

The 1979, 1981, and 1983 studies found that about 14 percent of American adults thought that they were "very well informed" about issues pertaining to science and technology. (See table 7-2.) This is well below the number who feel well informed about the economy and business conditions, but comparable to the number feeling informed in the other areas. The proportion feeling well informed about science and technology issues has increased by about four percentage points over the last five years, paralleling an increase in the percent feeling informed in several other areas. In contrast to the substantially higher levels of interest reported above, these results on levels of perceived knowledge indicate that there are significant numbers of Americans—about 60 million—who have a strong interest in matters pertaining to science and technology, but who assess their own knowledge in this area as deficient.

The patterns of perceived knowledgeability for both energy policy and foreign policy illustrate the problem of maintaining public information concerning an issue area. In the energy area, the peak of public activity and media coverage in the 1970's and early 1980's was paralleled by an increase in the proportion of Americans who thought of themselves as being well informed about energy matters. However, the subsequent decline in activity and coverage has been followed by a decline in the proportion of persons classifying themselves as knowledgeable in this area. The Iranian hostage crisis apparently played a similar role in regard to the public's perceived knowledgeability about foreign policy issues. Public interest in foreign affairs rose during the period of the hostage crisis, and declined to pre-crisis levels within a few months after the end of the hostage situation.[8]

The proportion of adults who think of themselves as being well informed about science or technology increased significantly between 1979 and 1983 among non-college-educated women in all age classifications and among non-college-educated men aged 55 and over. (See appendix table 7-3.) As noted above, the longer a set of issues is on the national agenda, the more accessible it becomes to all citizens, regardless of their formal education. This increased accessibility comes, in part, from the repeated coverage of issues in newspapers, news magazines, and other media addressed to mass audiences.

The level of perceived knowledgeability among college students was comparable to the level for adults generally. In view of students' exposure to science and public affairs courses, a higher level of perceived knowledgeability might have been expected. In absolute terms, however, almost 9 out of 10 college students do not think of themselves as being well informed about science and technology issues.

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[6] Miller, Prewitt, Pearson (1980), Miller (1983a).

[7] Ibid.

[8] Gallup (1980, 1982).

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Table 7-2. Public perception of its knowledge about selected policy issues: 1979-83

	All adults			College
Percent "very well informed" about...	1979	1981	1983	1983
Economic issues and business conditions	14	30	28	15
New scientific discoveries	10	13	14	12
Use of new inventions and technologies	10	11	14	10
Energy policy	18	24	19	13
International and foreign policy	9	18	14	10
Space exploration	NA	14	13	13
N =	1,635	3,195	1,630	2,011

"Now, I'd like to go through this list with you again and for each issue I'd like for you to tell me if you are very well informed about that issue, moderately well informed, or poorly informed."

SOURCES: Miller, Prewitt, Pearson (1980), Miller (1982, 1983c, 1984).

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Among college students, a higher proportion of males than females thought of themselves as being well informed about these issues in all demographic classifications. (See appendix table 7-4.) Students planning a scientific or public service career[9] were more likely to think themselves as being knowledgeable than were other students, and this difference was especially pronounced among female college students.

ATTENTIVENESS TO SCIENCE AND TECHNOLOGY

Several studies[10] have argued that a high level of interest and the perception of knowledgeability in an issue area combine to produce a citizen who effectively follows that issue. This person acquires information about the issue and is significantly more likely to take some action to influence policy. Such citizens are referred to as being "attentive" to a given policy area and, in the aggregate, they are referred to as the "attentive public" for a given issue area. Following this approach, those respondents in the 1979-83 studies who reported that they were both very interested in and well informed about either new scientific discoveries or the use of new inventions and technologies were classified as attentive to science and technology policy.[11]

An examination of the proportion of Americans attentive to science and technology policy found a small but steady increase during the period from 1979 to 1983. (See table 7-3.) By 1983, almost a quarter of the American people qualified as attentive to science and technology issues.

There are some people who do not qualify as attentive because they do not feel knowledgeable about scientific and technological matters, although they have a high level of interest in those subjects. These individuals have been called "the interested public" for science and technology policy.[12] Since they are interested, they are more likely to follow scientific and technological issues than are the other nonattentives. They are also the pool from which new attentives are likely to come. The proportion of Americans who were interested—but not attentive—in science and technology policy increased from 1979 to 1983, reaching 28 percent. (See table 7-3.) This increase took place mainly between 1981 and 1983.

Since 1979, significant growth in the attentive public has occurred among non-college-graduates aged 55 and over. (See appendix table 7-5.) In 1979, persons aged 55 and over were significantly less likely to be attentive to science or technology issues than other citizens, but by 1983 the proportion of attentives among this group paralleled the average for all groups. This result is consistent with the idea that exposure to an issue area over a period of years increases citizens' access to those issues.

In summary, from 1979 to 1983 substantial increases occurred in the proportion of adults who reported a high level of interest in science or technology, but little gain occurred in the proportion that felt well informed about such issues. By 1983, almost a quarter of the American people—over 42 million adults—expressed a high level of interest in science or technology issues, indicated a feeling of being well informed about those issues, and engaged in

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[9] An analysis of the proportion of students attentive to science and technology issues found that those students planning careers in basic science, applied science, engineering, education, or public management were significantly more likely to be attentive to science and technology issues than students planning careers in other fields. For the purpose of analytic clarity, occupational preference was grouped into the combination of scientific and public service careers versus all other choices.

[10] Almond (1950), Miller (1983a), Miller, Prewitt, Pearson (1980).

[11] In the actual determination of attentiveness for this analysis, an additional defining factor was used. A respondent also had to demonstrate a pattern of sustained information acquisition relevant to science and technology policy by reporting that he or she regularly engaged in two or more of the following activities: (1) watching the television news, (2) reading a news magazine, (3) reading a daily newspaper, or (4) reading a science magazine.

[12] Miller (1983a).

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Table 7-3. Attentiveness to and interest in science and technology: 1979-83

	All adults			College
Percent of public . . .	1979	1981	1983	1983
Attentive[1]	19	20	24	25
Interested but inadequately informed	21	18	28	22
Not interested or attentive	61	62	47	53
N =	1,635	3,195	1,630	2,011

[1] Both "very interested" and "very well informed" about science or technology.

SOURCES: Miller, Prewitt, Pearson (1980), Miller (1982, 1983c, 1984).

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a regular pattern of relevant information acquisition. This attentive public is the segment of the American public that is most likely to monitor the formulation of science and technology policy in the United States. By comparison with agricultural or economic policy, the formulation of science and technology policy has only rarely involved substantial public participation. However, if future issues should generate broader public input into the process, that participation will come primarily from this attentive public for science and technology.

SCIENCE AND TECHNOLOGY POLICY ATTITUDES

After defining three strata of public interest and knowledgeability about science and technology issues, it is appropriate to turn to the substantive views of the American people about science and technology. What impact do Americans think that science and technology have had on their lives in the past and what impact do they expect in the future? How do Americans view the growth of computer utilization, especially in manufacturing? How willing are Americans to have governmental restraints placed on the work of scientists and engineers? This section will examine these questions, looking at both the overall attitudes of the total adult population and, when possible, the views of the three groups identified in the preceding section.

A Retrospective Assessment of Science and Technology

In broad terms, an overwhelming majority of Americans believe that science and technology have made their lives healthier and easier, and expect future prosperity based on the same contributions from science and technology. (See table 7-4.) A quarter century ago, a 1957 opinion survey[13] found that 94 percent of Americans agreed with the identical statement and that only 3 percent disagreed.[14] Although the level of positive assessment has declined, the relative stability of these attitudes over the last 25 years is a remarkable commentary on the relationship between the scientific and technical communities and the larger society.

Reflecting this positive evaluation of the past contribution of science and technology, 9 of 10 Americans interviewed in a 1983 survey agreed that the future prosperity of the United States will depend on "more and better technology." (See table 7-4.) A majority of the American people expected science and technology to solve "most of the economic and social problems that we face today," but a full third of the public expressed doubts that science and technology would be able to solve social and economic problems as effectively as physical and engineering problems.

There is wide recognition among the public that science and technology simultaneously offer the promise of plenty and potential danger. Three-quarters of the people polled in a 1983 survey[15] expressed concern that the development of nuclear, chemical, and biological weapons could destroy the human race. A parallel study[16] of selected leadership groups found that this view was shared by 71 percent of a sample of Congressmen and top aides, 69 percent of a sample of science editors, 64 percent of a sample of school superintendents, and 46 percent of a sample of corporate executives.

Although the specific objects of concern have changed over the last 25 years (i.e., from atmospheric testing of nuclear weapons to the placement of nuclear and laser weapons in space), the overall pattern of public attitudes has been remarkably stable.

Despite the potential hazards of science and technology, there is no evidence of a weakening of public support for scientific research. When asked whether scientific research should be supported "even if it brings no immediate benefits," 8 of 10 Americans endorsed the support of scientific research as worthwhile. (See table 7-4.) This view was shared by virtually all of the leadership groups. In 1957,

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[13] The 1957 survey is a landmark in the study of public attitudes toward science and technology. The field work was completed just two weeks prior to the launching of Sputnik I by the Soviet Union. This is our last and best measure of public attitudes toward science and technology prior to the beginning of the space age and all of its implications for the public's thinking about science and technology. For a description of the study, see Davis (1958).

[14] Davis (1958).

[15] Harris (1983), p. 129.

[16] Ibid.

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Table 7-4. Public perceptions of the effects of science and technology: 1983

	Agree	No opinion	Disagree	N
	Percent			
Science is making our lives healthier, easier, and more comfortable. (Miller, 1983)	85	3	12	1,630
The future prosperity of the United States depends on more and better technology. (Cambridge Reports, 1983)	88	3	9	1,466
Most of the economic and social problems we face today as a society will eventually be solved by technology. (Cambridge Reports, 1983)	58	8	34	1,466
Even if it brings no immediate benefits, scientific research, which advances the frontiers of knowledge, is a necessary human endeavor worth supporting. (Harris, 1983)	82	4	14	1,256
With the development of nuclear, chemical, and biological weapons, science and technology may end up destroying the human race. (Harris, 1983)	74	3	23	1,256
One trouble with science is that it makes our way of life change too fast. (Miller, 1983)	44	2	54	1,630
One of the bad effects of science is that it breaks down people's ideas of right and wrong (Miller, 1983)	29	7	65	1,630

SOURCES: Cambridge Reports (1983, 1984), Harris (1984), Miller (1983c).

Science Indicators—1985

43 percent of the public expressed the view that science makes our way of life change too fast.[17] A 1983 survey found that 44 percent of the American people still held the same view.[18] Similarly, the 1957 survey found that 23 percent of those respondents were concernedthat science might break down people's "ideas of right and wrong." In 1983, 29 percent of American adults expressed the same concern.

An analysis of these attitudes indicates that citizens who are attentive to science and technology issues are significantly more likely to hold positive views of the effects of science on the quality of American life and to be less concerned about potential hazards. (See table 7-5.) Citizens who were interested in science or technology issues but who did not think of themselves as being well informed about those issues (the interested public) were more positive toward the contributions of science than citizens not interested in the issues, but less so than the attentive public.

Attitudes Toward Recent Technological Developments

Looking at more contemporary technological developments, surveys in 1983 found that the public was able to differentiate between those technologies that it evaluates

Table 7-5. Perceptions of the effects of science and technology, by level of attentiveness: 1983

Percent agreeing that...	Attentive public	Interested public	Balance of public
Science is making our lives healthier, easier, and more comfortable. .	92	88	79
One trouble with science is that it makes our way of life change too fast. .	37	41	54
One of the bad effects of science is that it breaks down people's ideas of right and wrong.	23	27	36
N =	398	462	770

"Now I'm going to read you some statements about science. After I read each one, please tell me whether you tend to agree or disagree with it."

SOURCE: Miller (1983c).

Science Indicators—1985

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[17] Davis (1958).
[18] Miller (1983c).

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positively and those about which it has reservations.[19] One survey[20] asked respondents to indicate whether or not they expected various technological developments to make the quality of their life a lot better, somewhat better, somewhat worse, or a lot worse. The results indicated that at least three-quarters of the public thought that computers, electronic calculators, and laser beams were positive technological developments. (See table 7-6.) A majority of the adults surveyed also thought that permanent space stations, genetic engineering, and robots and automation would improve the quality of their lives.[21] In short, several of the major results of science and technology appear to have been well received by the American public. In contrast to the positive reactions to other scientific and technological developments, the relatively higher level of negative evaluation of nuclear power indicates a public divided almost equally on this issue.[22]

Science, Technology, and Employment

Looking at other contemporary issues, recent studies of the public's view of the impact of science and technology on employment have produced a portrait of uncertainty and, perhaps, wariness. The proportion of the American public that believes that science and technology cause unemployment has fluctuated between 35 and 45 percent in recent years (see table 7-7), as has the portion believing that science and technology create jobs. These responses depend strongly on levels of income and education; those with high incomes and high education levels believe that science and technology lead to more employment, while less privileged Americans believe the opposite.[23]

The public appears to understand the dimensions of the problem and, at the same time, to accept the necessity of increased automation. (See table 7-8.) Almost three-quarters of the public expected factory automation to cause the unemployment of "hundreds of thousands" of American workers, but three-quarters of the public also agreed that American factories will be unable to compete with factories in other countries unless they automate. Over 40 percent of the American public indicated that computers will create more jobs than they will eliminate.

This pattern of attitudes reflects a public that is basically positive toward science and technology, but recognizes that negative impacts on employment and on specific industries may occur. Clearly, the public credits science and technology with substantial contributions to the current standard of living in the United States and expects additional positive results in the future. Most Americans

Table 7-6. Public evaluation of recent technological developments: 1983

Development	"Will make life better"	"Will make life worse"
	Percent	
Computer	88	9
Hand-held electronic calculator	87	8
Laser beam	76	13
Permanent space stations	70	14
Genetic engineering	67	16
Robots and automation	64	28
Nuclear power	48	44
N = 1,256		

"Now, let me ask you about some more recent developments. For each, from what you know or have heard do you think it will make the quality of life a lot better for people such as yourself, somewhat better, make it somewhat worse, or a lot worse?"

SOURCE: Harris (1984), p. 81.

Science Indicators—1985

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[19] Previous evidence that the public can make reasonably well informed judgments about various technologies was presented by LaPorte and Metlay (1975a, 1975b). Using data from a survey of California residents, they examined the public's understanding of several technologies and found a high level of ability to differentiate in terms of potential positive and negative effects.

[20] Harris (1983), p. 81.

[21] In assessing these results, it is important to understand the level of public awareness of new technologies like genetic engineering. A 1985 study asked a national sample of adults to explain what they thought of when they heard the term "genetic engineering." Almost 60 percent had no knowledge of the term and another 18 percent gave general or vague responses like "test-tube babies." Only one in five respondents gave a response that suggested any understanding of the term. (Cambridge Associates, 1985.)

[22] For a review of the relevant empirical literature on public attitudes toward nuclear power, see Nealey, Melber, and Rankin (1983).

[23] Cambridge Associates (1985).

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Table 7-7. Public perceptions of the impact of science and technology on employment: 1983-85

Percent agreeing that scientific and technological changes	1983	1984	1985
Cause unemployment	40	45	35
Cause job increases over the long run	42	35	45
Don't know/not sure	19	20	20
N =	1,466	1,862	1,864

"Some people say that scientific and technological changes cause unemployment because people's jobs are replaced by machines. Others argue that, while some jobs may be lost in specific areas, scientific and technological changes increase the total number of jobs over the long run. Which view do you think is closer to the truth"?

SOURCE: Harris (1984), p. 81.

Science Indicators—1985

Table 7-8. Public perceptions of the impact of computer-based technologies on employment: 1983

	Agree	No opinion	Disagree
		Percent	
Factory automation will put many hundreds of factory employees out of work in this country in the next five years. (Harris)	71	2	27
If we don't automate our factories, American products will be too expensive to compete successfully against products made in automated factories in Japan and Europe. (Harris)	74	3	23
One of the main reasons why there is high unemployment in this country is that technological developments have put many Americans out of work. (Harris)	55	2	43
Companies place too much emphasis on machines and new technology and not enough on the workers who use them. (Cambridge)	72	5	22
On balance, computers will create more jobs than they will eliminate. (Miller)	42	6	52
N for Cambridge Reports =	1,466		
N for Harris =	1,256		
N for Miller =	1,630		

SOURCE: Cambridge Reports (1983, 1984), Harris (1984), Miller (1983c).

Science Indicators—1985

recognize the need for increased automation, but many apparently fear significant job losses in their own industries.

In contrast, approximately 90 percent of a national leadership sample surveyed in 1983 held the view that factory automation was necessary to make American products competitive in world markets.[24] However, these leaders were significantly less likely to predict that factory automation would lead to substantial additional unemployment. Among the 100 corporate executives included in the Harris study, only a third thought that automation would lead to higher unemployment.

Computers and Society

Computers have other impacts on society. Recent surveys indicate that over three-quarters of the American people recognize the speed of computers, the freeing of human

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[24] Harris (1983), pp. 130–31. The leaders were Congressmen and top aides, corporate executives, science editors, and school superintendents.

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time from repetitive tasks, and the stimulation of new learning opportunities. (See table 7-9.) Over 90 percent of the public realize that computers can do only what they are told, and 83 percent believed that "almost anyone can learn to use a computer." Actual computer usage appears to be more broadly distributed than previously thought. Forty-five percent of the public reported that they had some knowledge of how to use a computer.[25] When asked to assess their own skill level, 29 percent labelled themselves a beginner and 13 percent claimed an "intermediate" level of skill. Only 3 percent thought that they could be called an "expert." Another 1983 survey[26] found that 9 percent of American homes claimed to own a home computer, but only a quarter of those units had a central processor of 36K or more. A 1985 survey found that 11 percent of adults "use a computer" in their job.[27] Despite the portrayal in film, television, and science fiction of computers that think or have personalities, most American adults think of computers as tools that are potentially accessible to persons like themselves and not elitist, technocratic, or evil.

At the same time, 88 percent of the public expressed an awareness that computer-based data banks provide an opportunity for the unauthorized or improper modification of records. (See table 7-9.) Virtually the same percentage of the national leadership sample[28] expressed the same concern. Half of the public was willing to agree that "some day" computers might be running our lives, while more than half expressed concern that computers would be able to increase the institutional control of individual workers' time, thus creating "human robots." A 1985 survey found that 26 per cent of American adults thought that computers pose a "very serious" threat to personal privacy.[29] Since most of this wariness seems to be future-oriented, it appears that the public has a reasonable and accurate image of the current impact of computers on society but is less certain how computers might be employed in the future. The public appears to recognize that the computer, like science and technology generally, simultaneously offers the opportunity to improve our standard of living and the potential for abuse.

When asked specifically to assess the positive and negative impact of the computer on society, however, a solid majority of Americans reported that the computer has done more good than harm (see table 7-10), and far fewer were willing to say that the computer had caused more harm than good. A separate analysis found that the view that

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[25] Harris (1983), p. 60.
[26] Miller (1983c).
[27] Cambridge Associates (1985).
[28] Harris (1983), p. 133.
[29] Cambridge Associates (1985).

Table 7-9. Public perceptions of the impact of computers on society: 1983

	Agree	No opinion	Disagree
	Percent		
Computers can solve problems in a few days that used to take years or months to do. (Harris)	91	2	7
Computers can free up time for individuals to do creative and highly productive work. (Harris)	85	2	13
In education, computers will allow talented students to go much further in their studies and learn much more than they do now. (Harris)	78	2	20
Computers can only do what people tell them to do. (Miller)	91	2	7
Almost anyone can learn to use a computer. (Miller)	83	2	15
Computers open up the real possibility of vital records being tapped and tampered with by outside computer meddlers. (Harris)	88	3	9
Someday, computers may be running our lives. (Miller)	49	1	50
Computers can make human robots out of workers by controlling every minute of their day. (Harris)	55	3	42
N for Harris =	1,256		
N for Miller =	1,630		

SOURCE: Harris (1984), Miller (1983c).

Science Indicators—1985

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Table 7-10. Risk-benefit assessment of computers: 1983-85

Percent responding . . .	1983	1984	1985
More good than harm	59	55	58
More harm than good	7	11	7
About the same of each	28	28	30
Don't know	6	6	5
N =	1,466	1,863	1,863

SOURCE: Cambridge Reports (1983, 1984, 1985).

Science Indicators—1985

computers caused more harm than good was held predominantly by older respondents and by persons with only a grade-school education.

In summary, the preceding analysis indicates that the public recognizes the contemporary impact of science and technology on their lives, that they can and do make differential evaluations of those impacts, and that most Americans hold a balanced view of the positive and negative effects of these forces. The positive contributions of science and technology to our standard of living are recognized by almost all American adults included in these studies. However, the short-term negative impact of automation on employment is also recognized, and there is a discernible wariness among the public about nuclear power.

Future Expectations for Science and Technology

Building on a positive view of the past contributions of science and technology and an understanding of contemporary impacts, Americans report a high level of expectation for future achievements in a wide array of areas. A majority of the American public now think that it is "very likely" that researchers will find a cure for the common forms of cancer in the next 25 years. (See table 7-11.) In contrast, almost half of the American people think that it is "not likely" that researchers will make a major contribution toward a cure for mental retardation during the same period. These results indicate that the public is capable of making some distinctions about the probable future impact of science and technology in the medical field.

The public demonstrated a similar ability to differentiate in regard to future space exploration activities. In 1979, only 17 percent of American adults thought that it was very likely that "communities of people" could be put into space in the next 20 years. But in 1983, a majority of Americans thought that people would be working in space stations within the next 25 years. (See table 7-11.) This difference reflects in part the successful launch of the space shuttle program and the public's observation of astronauts working within the shuttle environment. Also, the 1979 reference to "communities" implied larger numbers of people and likely increased the public's doubts about the feasibility of placing larger groups of people in a functioning environment within two decades. Public sophistication was also evident in that only a small minority of the American public thought it very likely that scientists and engineers would be able to communicate with alien beings within the next 25 years, despite the wide exposure to the E.T. and Star Wars stories. A significant portion of the American public, however, is troubled by the prospects of wars in space, using space-age weaponry. A quarter of the public

Table 7-11. Public expectations concerning the future outcomes of science and technology: 1979-83

Outcome	Year	Very likely	Possible but not likely	Not likely at all	N
		Percent			
A cure for the common forms of cancer	1979	46	44	8	1,635
	1983	57	36	6	1,630
A cure for mental retardation	1983	11	40	47	1,630
A way to put communities of people in outer space.	1979	17	38	42	1,635
People working in a space station	1983	52	34	12	1,630
Humans communicating with alien beings	1983	14	33	51	1,630
Wars in space	1983	26	36	36	1,630
More efficient sources of cheap energy	1979	57	34	7	1,635
A safe method of disposing of nuclear wastes . .	1983	29	41	26	1,630

"Now, let me ask you to think about the long-term future. I am going to read you a list of possible scientific results and ask you how likely you think it is that each of these will be achieved in the next 25 years or so."

SOURCES: Miller, Prewitt, Pearson (1980), Miller (1983c).

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thought it was very likely that there would be wars in space within the next quarter century and even more thought that it was "possible, but not too likely."

In the energy area, the public expected researchers to find less expensive and more efficient energy sources during the next 20 years. However, only 29 percent thought that it was very likely they would find a safe way to dispose of nuclear wastes, indicating awareness of the difficulties in this area.

In general, citizens who are attentive to science and technology issues are even more optimistic about future achievements. In both 1979 and 1983, the attentive public for science and technology was significantly more likely to believe that research would find a cure for the common forms of cancer within the next two decades than were citizens who expressed no interest in science or technology. (See appendix table 7-7.) Similarly, persons attentive to science and technology were significantly more likely to expect that people will be working in space stations within 20 years and that safe methods will be found to dispose of nuclear wastes. Attentives were slightly more likely to think that wars would occur in space than persons who were not attentive.

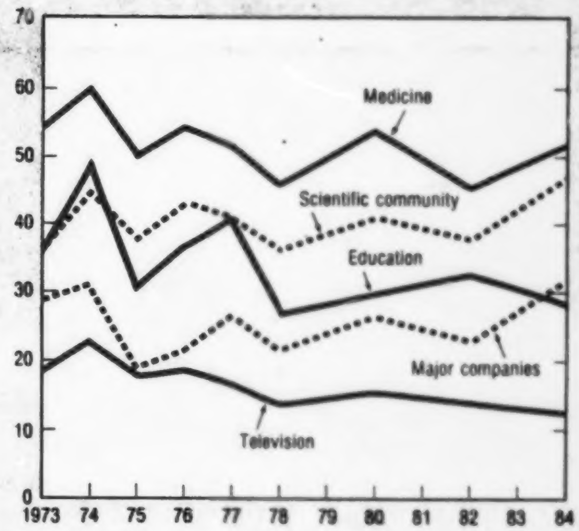
Public Confidence in Science and Technology

The positive attitudes toward past contributions from science and technology, the high expectations for the future, and the balanced view of the impact of science and technology on employment all reflect a high level of public confidence in the scientific community. For over a decade, the General Social Survey has been asking Americans how much confidence they have in the leaders of selected institutions.[30] An examination of the results of those surveys indicates that the scientific community continues to be held in high regard, with 47 percent of Americans reporting that they have a "great deal of confidence" in the leadership of the scientific community. (See figure 7-1 and appendix table 7-8.) Of those institutions included in the study, only the leadership of American medicine is held in higher regard and the margin of difference has been diminishing over the last several years. The public reported a significantly higher level of confidence in the leaders of the scientific community than in the leaders of education, major companies, television, the press, and the military.

Further, after weighing the positive and negative results of science and technology, the public has concluded that the balance is on the positive side. In 1983, over 70 percent of American adults agreed that science and technology had caused more good than harm. (See table 7-12.) In 1985, the percentage of Americans agreeing with this view had dropped to 58 percent, however.

The 1957 survey discussed above asked respondents "All things considered, would you say that the world is better off or worse off because of science?" Over 80 percent of the public expressed the view that the world is better off.[31] In this context, the generally positive pattern shown in table 7-12 may be viewed as a continuation of long-term popular support of science and technology in the United States.

Figure 7-1
Percent of the public expressing a great deal of confidence in the people running selected institutions



See appendix table 7-8.

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The Regulation of Science and Technology

The preceding discussion has focused primarily on the attitudes of Americans toward the past, current, and future impacts of science and technology on society. Inherent in these attitudes is the power of the public, through government, to exercise more overt control over the work of scientists and engineers. An examination of the public's willingness to impose restraints on scientific inquiry found that most Americans were unwilling to prohibit studies on most topics, but in the area of the creation of life, public concern was much greater. (See table 7-13.) Large numbers were willing to prohibit studies intended to create new life forms or to make it possible for future parents to select the sex of their child at the time of conception. These results point toward a strong public concern about research that modifies life forms, especially human life forms.

The same data indicate that the attentive public for science and technology is significantly less likely than other segments of the population to wish to restrain inquiry. For example, only 19 percent of the attentive public would be

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[30] Davis and Smith (1985). In-depth studies of this question have found that most respondents do not have specific individuals in mind when they evaluate the leadership of these institutions. Rather, these responses should be viewed as representing a subjective assessment of the contribution of the institution to society. For an analysis of these confidence data and a report on some methodological research on these measures, see Smith (1981).

[31] Davis (1958).

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Table 7-12. Public perceptions of the risks and benefits of science and technology: 1972-85

Response, in percent	Do more good than harm	Do more harm than good	About the same, amount of each	Don't know not sure	N
1972	54	4	31	11	2,209
1974	57	2	31	10	2,074
1976	52	4	37	7	2,108
1983	73	3	21	3	1,466
1984	63	5	27	5	1,864
1985	58	5	32	5	1,866

"Overall, would you say that science and technology do more good than harm, more harm than good, or about the same amount of each?"

SOURCES: Opinion Research Corporation (1972, 1974, 1976), Cambridge Reports (1983, 1984, 1985).

Science Indicators—1985

willing to prohibit genetic engineering studies to create new forms of plants and animals, while 29 percent of the interested public and 52 percent of the rest of the public would be willing to impose such restrictions. (See appendix table 7-9.) Only 18 percent of the attentive public would seek to stop efforts to locate other intelligent life in the universe, while a quarter of the interested public and a majority of the rest of the public would oppose inquiry in this area. The same pattern of responses occurs when the three groups are asked whether they would be willing to prohibit research directed toward selecting the sex of children.

Table 7-13. Public willingness to restrain scientific inquiry: 1979-83

Percent willing to prohibit. . .	1979	1983
Studies that might enable most people in society to live to be a 100 or more.	29	32
Studies that could allow parents to select the sex of their child.	NA	62
Studies that might allow scientists to create new forms of life.	65	NA
Studies that could allow scientists to create new forms of plant and animal life.	NA	46
Studies that might lead to precise weather control and modification.	28	NA
Studies that might discover intelligent beings in outer space.	36	38
N =	1,635	1,630

"In terms of some specific kinds of research, do you think that scientists should or should not be allowed to conduct: ...?"

SOURCES: Miller, Prewitt, Pearson (1980), Miller (1983c).

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OVERVIEW

Three primary conclusions emerge concerning the levels of interest and knowledge of the American people about science and technology, and their attitudes toward science and technology policy matters.

First, an increasing proportion of Americans is interested in scientific and technological matters. Beyond the survey evidence reviewed above, the prevalence of science and technology themes in films, television, and published fiction reflects the scientific and technological character of our current culture. The growing numbers and rising sales of popular science magazines and of home computers reflect the same influence. Similarly, the increasing number of science- and technology-oriented television series and the apparent growing audience for those shows indicate a growing level of public interest.

Second, the growth of interest in science and technology has not been paralleled by an increase in the public's sense of knowledgeability about scientific and technical matters. Despite the substantial increases in the purchase and consumption of popular scientific and technical materials of all types, only 14 percent of the American people think of themselves as being well informed on these matters. A separate analysis of the data from a 1979 survey[32] found that only 7 percent of the American people qualified as scientifically literate. This gap, between interest and both perceived knowledgeability and literacy, is troublesome. Minimally, it suggests that current efforts at increasing the public's understanding of science and technology are having only limited success. In broader terms, it means

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[32] Miller (1983b).

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that there are about 60 million American adults who have a strong interest in scientific and technological matters and who therefore might be brought into the policy formulation process. But these people lack an adequate understanding of science and technology both by their own perceptions and by more objective yardsticks. While science and technology policy matters are rarely electoral issues, these data suggest that many Americans would have difficulty making an informed decision if science or technology policy issues were thrust into a broader electoral arena.

Third, this analysis found the American people to be strongly supportive of science and technology. They believe that much of the prosperity of recent decades can be attributed to the contributions of science and technology, and their expectations for the future are even higher. There is a reasonably sophisticated understanding that science and technology do cause changes, but that the benefits of these changes outweigh the costs of change. From these results, the post-war "contract" between society and the scientific and engineering community—innovation and prosperity in exchange for support and independence—appears to have strong and continuing support. The American public still looks to science and technology to provide an improved, though always changing, quality of life.

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Chapter 8
Advances in Science and Engineering

ADVANCES IN SCIENCE AND ENGINEERING: THE ROLE OF INSTRUMENTATION

INTRODUCTION

The ability to describe an increasing range and variety of natural phenomena in mathematical terms has been a hallmark of scientific advance for more than 300 years. As Galileo wrote in 1608:

> Philosophy is written in this grand book, the universe, which stands ever open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics . . . without which it is humanly impossible to understand a single word of it.

Implicit in Galileo's prescription for the advancement of science are requirements for several distinct but related capabilities including, the abilities to make precise, quantitative determinations of the critical parameters that characterize a given process or phenomenon, and to manipulate the resultant experimental or observational data mathematically. Thus, the development of improved techniques for making measurements and performing calculations has been a persistent, central theme in the evolution of science and of engineering. Indeed, that theme provides one of several essential links between advances in those separate but related areas. Improvements in scientific instruments, including computers, are in large measure the products of advanced technologies, and in that sense advances in engineering precede advances in science. But the impetus for applying advanced technologies to improve scientific instruments often derives from the needs of a scientific discipline. Moreover, current frontier technologies are invariably based on frontier science. So in both senses, advances in science precede advances in engineering. Thus, even a cursory examination of the role of instrumentation in science and engineering belies the naive notion that advances occur by means of a simple, linear progression—from basic science, to applied science, to engineering development, to commercialization. Rather, basic science, instrumentation, and engineering development form a loop in which creativity travels in both directions.

This chapter consists of five case studies illustrating the important and often synergistic roles that refinements in measuring and computing technologies play in undergirding and linking advances in science and engineering. These studies highlight spectroscopy, lasers, superconductivity, monoclonal antibodies, and computers. They also suggest the power of instrumentation in establishing couplings across scientific disciplines. Classes of instruments originally developed for use in one field frequently find uses in other, related fields, and in the process inevitably expand the scope of those fields. Finally, and not surprisingly, advanced scientific instruments, as products of advanced technology, are very often adapted for a variety of commercial purposes.

OVERVIEW

Spectroscopy

The optical spectrometer, which separates light into its components on the basis of their wavelengths, was originally developed during the 18th century as a means for studying the nature of light itself. It then evolved into a tool for studying the structure of matter, as improved instruments revealed that every chemical element and compound is characterized by a unique series of spectral lines. Early in the 19th century, recognition of the uniqueness of atomic and molecular spectra also led to the first systematic means for investigating extraterrestrial matter. This was achieved when Joseph Fraunhofer demonstrated that the characteristic dark lines previously observed in the solar spectrum could be used to study the chemical composition of the sun. Fraunhofer's discovery also provided another link (in addition to the study of gravity) between physics and astronomy.

Spectrometers have now been developed to probe the entire electromagnetic spectrum, providing a set of tools to make precision wavelength measurements from the ultrashort, gamma-ray end of the spectrum, to its long-wavelength, radio frequency end. Wavelength is inversely proportional to the energy of the molecular, atomic, or subatomic process leading to the emission of the radiation. Therefore, spectroscopy can be used, at one extreme, to study highly energetic interactions of elementary particles, or, at the other, the very low energy interactions occurring in the cold, diffuse interstellar medium. Meanwhile, mass spectrometers, which employ combined electric and magnetic fields to sort charged particles or ions on the basis of

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mass, have been developed to cover the range from the lightest atom, hydrogen, up to masses 1000 times greater that characterize molecules of interest in biochemistry.

A recurring motivation for improving existing types of scientific instruments is the need to separate or isolate relatively rare process or phenomena from other competing, often overwelming processes so that the former can be studied with precision. Advances in all types of spectroscopy have led to spectacular improvements in this respect. Very weak radiations from celestial objects, for example, can now be identified against stronger background radiation. In the case of the mass spectroscopic, and the distantly related nuclear magnetic resonance and electron spin resonance spectroscopic techniques, trace substances present in mixtures at levels of a few atoms or molecules per billion or even a per trillion can be detected and their concentrations precisely measured. These refinements have greatly extended the utility of these measuring technologies, making their use routine in fields such as atmospheric science where they were virtually unknown a decade ago.

Lasers

Developments in laser technology during the 25 years since the instrument was invented have proceeded in several directions, each seeking to exploit more fully one of the special characteristics of the instrument for scientific or commercial purposes.

Ordinary light sources (both artificial sources such as flames or incandescent and fluorescent lamps, and natural sources such as the sun and stars) produce light that is non-monochromatic (consisting of a mixture of frequencies) and incoherent (a superposition of wavelets emitted randomly, or incoherently, by the atoms or molecules of the source). In contrast, lasers produce light that is both monochromatic and coherent. Because of its coherence, laser light is also intense and highly parallel. Because highly monochromatic radiation of a specific frequency (or, equivalently, energy) excites only those atoms or molecules capable of absorbing energy at that frequency, such radiation is a boon to the study of atomic processes. However, invention of the laser had to await sufficient advances in fundamental knowledge about collective quantum effects in matter.

The utility of the first lasers was limited by their ability to produce light only in the long-wavelength, red portion of the visible spectrum. Thus, one obvious direction for development was to devise instruments to produce light in other spectral regions. Today, the available frequency range of lasers extends downward into the ultra-violet region, and upward into the infra-red region, even as the monochromaticity of the light produced continues to improve. Whereas the earliest lasers yielded light of one particular wavelength (depending on the type of laser used), today tunable lasers can produce monochromatic light of any desired frequency over relatively broad regions of the spectrum.

Another obvious direction for development was to increase available intensities. Today, pulsed lasers yield highly intense, monochromatic pulses lasting for as little as a few million-billionths of a second (i.e., a few femtoseconds or 10^{-15} seconds).

A final, obvious direction for development was to decrease the size and power consumption of lasers. As a result, research on semi-conductor diode lasers has led to miniature devices with dimensions comparable to transistors which can be used as integral components of electronic circuits.

These different types of improvements have been driven by, and exploited for, different kinds of applications. Highly monochromatic radiation of a specific energy (or, comparably, a specific frequency or wavelength), which only excites atoms or molecules capable of absorbing that energy, can—as already noted—be used for sorting or labeling those atoms or molecules. The availability of highly monochromatic radiation in short pulses adds time-specificity to energy-specificity. This feature makes it feasible to study interactions between atoms that occur over comparably short periods of time, and has made the laser an indispensable tool in studying conventional chemical reactions. The intensity of laser beams, coupled with their energy- and time-specificity characteristics, has extended their utility into other fields, including surface chemistry, biochemistry, and the neurosciences. Meanwhile, the virtually pure wavelengths of laser light have made the development of greatly improved standards of length possible, and (since wavelength and frequency are related reciprocally) have improved standards of time.

Because lasers deliver a highly focused, intense beam of energy, they can be used for precise, delicate cutting operations; this capability has led to applications in medicine and manufacturing. Lasers also show great promise in communications: like radiowaves and microwaves, coherent, monochromatic laser light can be modulated to serve as a carrier of information. But since the wavelengths of visible light are approximately 10,000 times shorter than even the shortest wavelength micro-waves, light guides or fibers less than a millimeter in diameter (as opposed to coaxial cables a centimeter or more in diameter) can be used for transmission purposes. With the advent of solid state lasers, the possibility now exists to miniaturize entire communications systems: transmitter, transmission channel, and receiver.

Superconductivity

The synergism between frontier science and frontier technology is well illustrated by the emergence of superconductivity from its status as a fascinating area of basic research, to the status of a technology that has already made significant improvements possible in scientific instrumentation, but also shows significant commercial promise. In 1911, H. Kammerlingh Onnes discovered that when mercury is cooled to a temperature below the liquefaction point of helium (4 degrees above absolute zero), it abruptly loses all measurable resistance to electricity; it becomes a superconductor, capable of sustaining an electric current indefinitely.

For more than 50 years after its discovery, superconductivity remained the province of a few small groups of low temperature physicists. During those years, additional superconducting elements and alloys were identified and their characteristics as superconductors studied. Investigations also showed that there is a maximum current that a given superconductor can carry before reverting to its normal state, and that a sufficiently intense magnetic field destroys or "quenches" superconductivity. But it has only been within the past 20 years that advances in materials science and technology have permitted applications of superconductivity for science and engineering purposes.

One of the most obvious of these applications is in the production of very intense magnetic fields. The intensity of the magnetic field produced by an electric current is proportional to the magnitude of the current. Electromagnets rely on currents flowing through their coils (usually made of copper wire) to produce a magnetic field. Unfortunately, currents in ordinary conductors such as copper also dissipate energy as a result of the resistivity of the conductor, with the energy dissipated proportional to the square of the current. As a result, field intensities attainable in conventional electromagnets are limited by two factors: the size of the power source required to maintain a continuously dissipating current in the magnet coils, and the heat generated in the coils by the dissipating current itself.

Since neither consideration is applicable to superconductors, the only limit, in principle, to the magnetic field that can be produced by a superconducting magnet (that is, a magnet with coils made of a superconducting material) is the maximum current at which that superconductor reverts to its normal state. However, non-trivial technical problems are involved in fabricating and operating such magnets on a usable scale. Virtually all known superconductors have mechanical properties that make them exceedingly difficult to fabricate into wire. Refrigeration systems capable of maintaining magnet coils at liquid helium temperatures are required. Finally, the superconducting state of a material can be "quenched," or destroyed by a magnetic field, requiring that superconducting magnets be designed and fabricated in such a way that stray fields do not destroy the superconducting current.

It is a tribute to imaginative work in materials science and technology that these difficulties have been surmounted. Large superconducting magnets are now producing intense fields for the proton accelerator at the Fermi National Accelerator Laboratory in Illinois and high field magnets of more modest dimensions are being used for one class of mass spectrometer.

Conceivable applications for superconducting magnets (as well as for other large-scale applications of superconductivity) are limited not so much by technological factors, but by insufficient fundamental knowledge of the process itself. In 1957, John Bardeen, Leon Cooper, and J.R. Schrieffer formulated a general theoretical explanation for the superconductivity phenomenon for which they were awarded a Nobel prize. But an understanding of specifics is still inadequate, so that predicting, for example, whether a particular hypothetical alloy will superconduct, and if so, at what temperature, cannot be done with any certainty. Given such specific fundamental knowledge, it might be possible to develop an alloy that would become a superconductor at liquid hydrogen or liquid nitrogen temperatures, or even at room temperatures. Such a material would simplify the refrigeration problem enormously, and thus make more widespread use of the technology possible. Superconducting magnets might then be used in the generation of electricity—in fusion reactors or in more conventional power generation sources. A material that superconducted at room temperature might also be used for power transmission over long distances with no appreciable loss.

Although these and other large-scale applications lie well in the future, efforts to gain a more detailed understanding of the fundamentals of the process have led to the discovery of unique collective quantum phenomena in superconductors that may lead to widespread applications of a different character. One such phenomenon, the Josephson effect, is the basis of the experimental Josephson junction, a very small and rapid electrical switch that may be applicable as the central switching element in future supercomputers. Josephson junctions are also the key element in so-called Superconducting Quantum Interference Devices which are being used to make exceedingly sensitive measurements of minute electric and magnetic field intensities. Even more recently, scientists investigating the quantum hall effect have discovered that, at extremely low temperatures, electrons within a superconductor behave as an entirely distinct state of matter. Although no immediate application of these latter findings is evident, the discovery's occurrence in a research setting where other investigators are seeking fundamental understanding that can be applied to specific purposes highlights the essential synergism between frontier science and frontier technology.

Monoclonal Antibodies

One of the recurrent themes illustrated by the case studies in this chapter is the cross-cutting, interdisciplinary character of scientific instrumentation; i.e., the frequent carryover of experimental techniques from one discipline into others. However, one way to distinguish among scientific disciplines is in terms of the types of problems that concern them. That is, there may be problems of burning interest in only one discipline or a small group of related disciplines. If so, the techniques used to attack such problems may also be highly discipline-specific.

The field of molecular biology is a case in point. Spectrometric and laser technologies, for example, are invaluable in the study of the physical and chemical properties of living cells. However, the problem of why biochemical molecules and living cells reproduce and grow is one about which neither physicists nor chemists are likely to have useful theoretical insights. Nor are the experimental instruments and technologies common to those fields useful for investigating all aspects of process and phenomena characteristic of living systems. For example, since lasers are now commonly used to identify and separate trace molecules from "dirty" mixtures, they can obviously be used to separate molecules of biological interest from highly complex living systems. Unfortunately, high intensity laser light also destroys what is ultimately most interesting about such systems: the fact that they are alive at all.

Beginning in the 1950's and continuing for approximately 20 years, many of the advances in the then emerging field of molecular biology were based on tools and insights derived from physics and chemistry. But more recent advances have occurred as a result of experimental technologies specific to molecular biology itself. Thus, the discovery and development of gene-splicing or recombinant DNA techniques in the early 1970's provided a powerful tool for exploring fundamental problems in cellular and molecular biology, as well as the promise of widespread applications in the pharmaceutical and agricultural industries and in medicine. The more recent discovery of monoclonal antibody techniques, highlighted as one of the case studies in this chapter, provides a second powerful set of tools both for studying fundamental biological and genetic process and for diagnosing and treating disease.

One recurrent technical problem in molecular biology is obtaining sufficient quantities of specific, pure reagents for research purposes. Many such substances have traditionally been obtained from animal or human organs, making them rare, difficult to purify, and expensive. Further, there are almost always subtle differences between samples of the "same" biochemical reagent obtained from two different animals of the same species. But monoclonal antibody techniques allow the production, or "cloning," of unlimited pure samples of biochemical substances from small numbers of cells and also assure that that substance will have precisely the same characteristics each time it is cloned thereafter. The possibility of producing pure biochemical reagents for research purposes also has obvious promise for production of much larger quantities for pharmaceutical purposes.

A fundamental characteristic of antibodies is their ability to seek out and attach themselves to specific molecules and cells. Monoclonal techniques permit the production of large quantities of specific antibodies, and therefore offer the capability of identifying and separating comparable quantities of molecules or cells from highly complex mixtures, such as human blood. It is this characteristic that makes the technique so useful for research in fundamental biology as well as for the diagnosis and treatment of disease, including cancer and autoimmune disorders. In a very real sense, the ability of monoclonal antibodies to identify traces of specific biochemical substances is analogous to the ability of laser light to identify and separate trace atoms or molecules in non-living mixtures. Even as exploitation of the sorting ability of lasers has led to spectacular advances in several fields of science and engineering, so spectacular advances in the biological sciences and in related engineering fields will almost certainly follow from the "exquisite specificity" of monoclonal antibodies.

Computers

The roles of advances in measuring technologies both in linking together and enriching various scientific disciplines and in undergirding advances in both science and engineering are illustrated repeatedly in the case studies that follow. The last of these studies describes the linkage or convergence between measuring and computing technologies.

Advances in computers during the past 40 years have, of course, been spectacular, and one of the most significant driving forces has been the need to perform lengthy and complex scientific calculations rapidly. Conversely, each sucessive advance in computer technology has drawn upon frontier results in a range of fundamental science disciplines. As computers have increased in speed and flexibility, their applications in science and engineering have multiplied and broadened. The earliest computers were used for making scientific calculations after the experimental data had already been gathered. Starting in the early 1960's, computers also came to be used for on-line data gathering and analysis as well as for the control and operation of scientific instruments. As such, they began to become integral components of such instruments.

Today, computers are being used increasingly as tools for discovery rather than simply as means for refining measurement techniques or for analyzing the results of data gathered with other instruments; they have achieved the status of scientific instruments in their own right. This convergence has occurred because of the enormous speed and memory capacity of present day supercomputers.

In several scientific fields such as number theory and statistical physics, for example, there are important classes of problems whose solutions, while understood in principle for some time, could not be worked out in useful detail until about a decade ago. This was because of the awesome number and complexity of the numerical calculations involved. Although modern computers do not make the solution of such problems exactly routine, at least they make them tractable. (See "Advances in Science and Engineering," *Science Indicators—1982*. p. 168.) The accessibility of specific solutions to problems in these and several other fields in which numerical complexity has stood as a barrier to advancement has been a stimulus to renewed interest in basic theoretical problems. Computers are now playing a role traditionally held by scientific instruments: they are providing refined data to challenge basic understanding and to stimulate advances in that understanding.

In several other fields such as geology, atmospheric science, and astrophysics, the speed of supercomputers, coupled with the availability of graphic displays, now makes it possible to simulate experiments that are otherwise impossible to carry out. For example, it is now possible to simulate, over the course of a few minutes, the movement of tectonic plates that actually occurs over millions of years and, by changing various assumed parameters, gain an understanding of the natural processes involved. Similarly, one can simulate different types of atmospheric conditions that may lead to the birth and evolution of tornadoes over several days, or witness the birth and evolution of stars over tens of millions of years.

The possibility of simulating complex experiments of this sort also has broad applicability in engineering. Indeed, applications of computer simulation now span virtually all engineering fields. For example, the same differential equations that describe the behavior of a hot plasma in an evolving star also describe a plasma in a fusion reactor. Thus, computers can be used to watch the behavior of plasmas under different conditions and they can also be used for reactor design. Likewise, the same general equations of fluid dynamics that are needed to describe the formation and evolution of tornadoes in the atmosphere are applicable to describe the motion of an object of a particular size and shape through the atmosphere. Thus, computer simulation has become essential in aeronautical engineering.

Victor Weisskopf, in concluding an essay on the evolution of matter from the relatively simple state represented by the hydrogen atom to the enormous complexity represented by human brain cells, characterized the human activity called science as "nature in the form of man [beginning] to contemplate itself." From that perspective, perhaps the most fascinating application of present day supercomputers is their use in helping to design their own descendants, descendants that promise to be a thousandfold more prodigious than their parents. Evolution has now apparently reached a stage at which human ingenuity can devise instruments that in some ways mimic human ingenuity itself. Advances in technology have not only made possible the attack on problems whose solutions were unthinkable a generation ago, but also have reached the stage at which they can help design systems for increasing the power of nature—as represented by the human mind—to contemplate itself.

SPECTROSCOPY

Much of our knowledge of the material universe comes from spectroscopy, the analysis of radiation absorbed or emitted by a substance and of the masses of its ionized subunits. Advances in scientific instruments used in such analyses allow researchers to explore nature in great detail on scales ranging from galaxies to atomic nuclei. The unreachable stars can be better understood through the light and other radiation that they emit. Unseeable molecules, whether trace contaminants or essential components of life, can be detected and their structure determined by using mass spectrometry. This technique involves separating ions of atoms and molecules by their mass and electric charge. Lasers and/or particle guns are combined with mass spectrometers to ionize selectively atoms and molecules and to fragment large, complex molecules. Such instrumental synergy "permits us to do experiments we did not even dream of doing only 5 years ago," notes Michael L. Gross, director of the Midwest Center for Mass Spectrometry at the University of Nebraska, Lincoln.

Optical Spectroscopy

Uses in Astronomy. Another synergy exists between new methods to capture light and techniques to extract information from that light. The spectra of starlight provides clues about chemical composition and temperature. Temperature, in turn, is a factor in determining stellar and galactic dimensions.

Spectroscopy also identifies molecules in planetary atmospheres. These molecules absorb particular wavelengths of sunlight. The rest of the light is reflected into a telescope, dispersed by a prism or diffraction grating, and separated into its component frequencies. The dark bands (absorbed wavelengths) and light bands (reflected light) in the resulting spectrum are cosmic fingerprints that identify each molecule. Fingerprints from planets and stars are compared with those from terrestrial molecules for positive identifications.

The spectrum of a bright speck twinkling in the night sky may reveal that it is not one, but two stars orbiting too closely to be resolved by telescopes. Changes in the movements of single stars can be detected by small shifts in the relative intensities of spectra taken at different times. Such changes in the radial velocity of a star may be due to an unseen planet.

A group at the University of Arizona in Tuscon has built a spectrometer to detect the first known planetary systems besides our own. The spectrum from a star is focused on a detector known as a charge-coupled device (CCD), which represents the latest in light detection technology. CCDs are used for all types of direct and spectroscopic imaging and they have made the 200-inch Hale telescope at Palomar Observatory in California into the keenest eye on Earth, capable of seeing fainter objects than have ever been detected by a ground-based instrument. Its "retina" contains four CCD arrays, each 800-by-800 pixels, originally manufactured for the Space Telescope. After they were rejected because of minor flaws, James E. Gunn of Princeton University adapted them for the Hale telescope. Called the "4 Shooter," this detection system went into operation in Spring 1984.

This system has already led to the discovery of what Gunn and his colleagues think is the "richest cluster of galaxies." It also will be used in an exciting application involving the study of images produced by gravitational lenses (intervening galaxies that bend light reaching Earth from distant quasars). The lens forms different images at different times because the length of the light paths vary. "The angles and times translate into distance," explains Gunn, "and this promises a more accurate way to measure very large distances than is now available." Some quasars may be as far away as 10 billion light-years; thus, this system would be a ruler of truly cosmic proportions.

CCDs not only require less exposure time, but they also permit measurements of a number of frequencies simultaneously. With photography and other types of electronic imaging, each frequency in a spectrum is measured separately. Presently available CCDs record 500 frequencies simultaneously, and those on the drawing boards should extend this capability to 10,000.

These frequencies can be measured in the infrared as well as in the visible parts of the electromagnetic spectrum. CCDs were used aboard the U.S.-British-Dutch Infrared Astronomical Satellite (IRAS), which performed the first all-sky survey at infrared wavelengths in 1983. The technology that made this possible included infrared and visible wavelength CCDs, a compatible spectrometer, a cryogenically cooled telescope, and cryogenic amplifiers.

Ground-based infrared observations before IRAS were limited to wavelengths between 8 and 25 microns. New CCDs made from gallium and germanium opened this IR window to 100-125 microns and also sharpened the previously blurry view at shorter wavelengths. Very weak infrared signals picked up and converted into electric currents by CCDs were intensified by new types of cryogenic amplifiers. Liquid helium cooled the telescope to about 2.5 degrees Kelvin (-270° C.) so that faint infrared radiation could be sensed above the heat noise generated by the spacecraft and onboard equipment.

These data have elated, surprised, and confounded astronomers. They include evidence of a dust ring around the star Vega, which may be a planetary system in the early stages of formation. New types of galaxies, barely luminous in the visible wavelengths, shine 50 to 100 times brighter in the infrared. Some of these may be pairs of galaxies in collision. One speculation is that shock waves from the collisions trigger the formation of new stars and release large amounts of infrared radiation. The birth of stars also shows up brightly in the infrared in normal galaxies, and IRAS data indicate that star formation is far more prevalent in the Milky Way than previously believed. Other IRAS discoveries include puzzling bands of dust in the solar system and in interstellar space, dust shells around the star Betelgeuse, new comets, and mysterious sources of emissions not yet correlated with any known object.

Atmospheric Studies. The focus of spectroscopy is not limited to distant stars and galaxies; spectrometers also make possible new kinds of studies of the atmosphere upon which we depend for survival. Examples include infrared spectroscopy to measure the distribution of temperature and trace gases such as water vapor, ozone, and nitric oxide. One effort has involved instruments from laboratories in seven countries being sent aloft in U.S. balloons. These flights were supplemented by data collected from aircraft, satellite, and ground instruments. The experimenters wanted to assess the accuracy of measurements of the chemical composition of the stratosphere by employing the largest available collection of instruments to measure a select number of trace gases at the same time in the same air mass. Such data will be used to test models of photochemistry in the stratosphere and will be applied to understanding how human activities are affecting the upper atmosphere. Of particular concern is depletion of ozone, which could increase the amount of ultraviolet radiation reaching the surface and consequently the incidence of skin cancer. Changes in the vertical distribution of ozone also may produce undesirable climate changes.

In addition to human activities, injection of gases and dust into the stratosphere by volcanic eruption can disrupt the ozone layer. Several groups have used spectroscopic and other techniques to measure the effect of the 1982 eruption of El Chichon in Mexico. Clyde R. Burnett of Florida Atlantic University and Elizabeth B. Burnett of the National Oceanic and Atmospheric Administration Aeronomy Laboratory in Boulder, Colorado, employed a ground-based ultraviolet spectrometer to follow changes in the vertical distribution of atmospheric hydroxyl (OH), which reduces the concentration of ozone. They recorded diurnal, seasonal, geographic, and solar cycle differences in OH abundances, including an increase of 30 percent in the summer of 1982, which was attributed to the El Chichon eruption.

Mass Spectroscopy

Spectrometers operating in the visible, infrared, and ultraviolet regions record absorption of sunlight by molecules in the atmosphere, or the emission of radiant energy as excited molecules relax to a ground state. The atmosphere also contains ions that can be detected by mass spectrometry. While this technique boasts a 70-year history, it has only recently been applied successfully to identify ions in the stratosphere and troposphere. In 1983, for example, researchers at the Georgia Institute of Technology used this technique for the first time to measure naturally occurring ions in the troposphere.

Instruments used in such experiments utilize magnetic fields to separate ions according to their mass and charge. Neutral samples must be ionized or fragmented before analysis. Physicists originally developed this technique to demonstrate the existence of isotopes by measuring differences in the masses of their ions. Early applications included mass determination of elements and elemental analysis. In the 1950's, higher field-strength magnets extended the range of mass spectrometers upward to include most small organic molecules—those with masses up to 1,000 atomic mass units. (One amu equals 1.66×10^{-24} grams.) In the 1960's, experimenters coupled mass spectrometers with gas chromatographs to separate mixtures of compounds into their component molecules before analysis, producing a powerful tool for separation and analysis of complex mixtures. The combination now is used in most basic and applied biological, biomedical, chemical, environmental, forensic, and pharmaceutical laboratories.

Uses in Chemical Analysis. Mass spectrometry involves both instruments and techniques for determining the structure of unidentified molecules and for identifying and quantitatively analyzing known compounds. Modern instruments are capable of both high sensitivity and specificity; they can detect quantities of a substance at levels as small as parts per trillion and identify unknowns at the level of parts per billion. The technique is undergoing a rapid expansion to larger, more complex molecules, such as catalysts and biomolecules. Commercial instruments now span mass ranges of more than 10,000 amu compared with 1,000 amu a few years ago.

New methods of creating ions, including bombarding a sample with laser or particle beams, have extended the limits of the technique from analysis of molecules in the gas phase to molecules in liquids and solids. Desorption of ions directly from a solid or liquid make it possible to obtain mass spectra of complex molecules such as peptides, antibiotics, and hormones.

New methods and instruments for integration of separation and analysis also are increasing the applicability of mass spectrometry. Separation of mixture components by liquid chromatography facilitates analysis of high-mass, nonvolatile compounds that cannot be handled by gas chromatography. Tandem mass spectrometry couples two mass spectrometers: one isolates a molecular ion of interest, the other analyzes it in detail. This approach combines high speed with the ability to search for either specific compounds or for groups of compounds having particular structural units. Tandem instruments used with samples ionized by the new desorption methods appear to be particularly promising for sequencing biomolecules such as peptides and nucleotides.

The high sensitivity of tandem mass spectrometry has been successfully applied to discover and establish the structure of drug metabolites, to find possible new drugs in plants, and to detect picogram quantities of drugs, food contaminants, and environmental pollutants.

Researchers expect that the details of reactions between ions and neutral molecules will be revealed by tandem spectrometry techniques. Important intermediates in such reactions would be isolated by one instrument and analyzed by a second. Especially promising are studies of the reactions of metal ions and neutral molecules which characterize metal complexes on catalytically active surfaces. Looking ahead further, mass-spectrometry experiments may use molecular beams to tailor surfaces to achieve chemical properties desirable in catalysis.

Uses in Biochemistry. For ionizing biological samples, fast atom bombardment (FAB) is the technique of choice. Samples in solution are bombarded with xenon or argon atoms having energies of 5,000 to 10,000 electron volts and both positive and negative ions are sputtered from the surface. "The technique is especially valuable in determining the sequence of amino acids in polypeptides," notes Kenneth L. Rinehart, Jr. of the University of Illinois at Champaign-Urbana.

Klaus Biemann and his colleagues at the Massachusetts Institute of Technology used FAB to confirm and correct amino-acid sequences in at least half a dozen large proteins whose primary structure had been determined from the base sequences of their corresponding genes. The protein is chemically cleaved in this technique to produce a pool of peptides which is partially separated by liquid chromatography. Each separated fraction then is subjected to fast atom bombardment mass spectrometry, which allows determination of the molecular weights of most or all of the peptides present in each fraction. These values are compared with the molecular weights of the peptides predicted from the DNA-deduced amino-acid sequence.

Fast atom bombardment mass spectrometry also has been used in combination with gas chromatography mass spectrometry to obtain the structure of a 112-amino-acid antitumor protein called macromycin. Small peptides produced by acid digestion of the protein were analyzed by the gas chromatography method and the results compared with molecular weights obtained by the fast atom bombardment technique.

Another advanced ionization-analysis combination pairs laser desorption and Fourier transform mass spectrometry (FTMS). The laser produces molecular ions and structural fragments from solid samples. With the FTMS, a scan of mass spectrum, the mixture for specific ions or for all fragments having a particular structure can be obtained *simultaneously*. FTMS offers exceptional mass resolution for this purpose. New commercial instruments combine all the functions of mass spectrometry, including ionization, in a single cell with dimensions of a few centimeters.

These techniques and instruments demonstrate how mass spectrometry has grown from its basic roots in physics to a tall tree with branches that include fundamental experiments and commercial applications in a broad variety of fields. About $200 million worth of instruments are purchased each year and several thousand people in the U.S. are engaged in utilizing them, according to R. Graham Cooks of Purdue University. The tree shows every sign of continued growth.

Nuclear Magnetic Resonance Spectroscopy

Advanced magnet technology represents an important nutrient for the growth of mass spectrometry. Higher field strengths translate into improvements in mass range, resolution, and measurement. They also have made possible striking gains in another rapidly evolving analytical technique, nuclear magnetic resonance (NMR) spectroscopy. While mass spectrometry relies on magnetism for separation of ions by their mass, NMR uses magnetism to line up atomic nuclei in a way that makes both spectral analysis and direct imaging possible.

First discovered in 1946, NMR spectroscopy today is one of the most widely used tools to determine the structure of newly isolated and synthesized molecules. Such analyses determine what elements and how many atoms of each a molecule contains, which atoms attach directly to each other by chemical bonds, what the length of the bond is, and what the angles between them are. The range of physical states that can be studied incorporates liquids, liquid crystals, solids, and gases. A molecule that has one three-dimensional structure as a solid may have others when in solution. Determining such changes lies beyond the reach of any technique but NMR spectroscopy. NMR permits identification of molecules absorbed on a surface, as well as characterization of reactions taking place on a surface. It also makes determination of protein and nucleic acid structures faster and simpler.

This technique exploits the behavior of atomic nuclei, which act like tiny bar magnets in a magnetic field. When placed in the field, they line up with it or against it. Nuclei lined up with the field have a slightly lower energy. If the atoms are exposed to precisely the right frequency of electromagnetic radiation, the lower-energy nuclei absorb it and flip to the higher energy state. This frequency is the resonance frequency detected by NMR spectroscopy. Such frequencies differ for different elements and vary as a function of the magnetic field strength; however, all fall in the radio frequency range.

The resonance frequency of nuclei of the same element is altered slightly by electrons and other nuclei in the same molecular neighborhood. Therefore, nuclei in different chemical circumstances in the same molecule absorb energy at slightly different frequencies. In the NMR spectrum, these appear as separate peaks. This effect reveals details of molecular structure and dynamics unattainable with other analytic methods.

In addition to such spectra, NMR produces whole body images and images of organs, tissues and cells. It is a valuable diagnostic tool, superior to computer-assisted tomography (CAT scanning) because it does not involve ionizing radiation. It allowed physicians to see bone marrow for the first time, and through a series of images, it can show a beating heart. The technique is also superior for diagnosing atherosclerosis, certain types of cancer, and diseases such as multiple sclereosis. Stuart Young of the Stanford University Medical Center calls NMR imaging "one of the greatest medical developments of all time." Michael M. Ter-Pogossian of the University of Washington School of Medicine in St. Louis predicts that, by 1986, every large radiology department in the U.S. will have an NMR unit.

NMR possesses the advantage of being non-invasive and non-destructive. "Unless somebody goofs, you can safely do NMR on the world's entire supply of an enzyme," comments George C. Levy of Syracuse University.

The stronger the magnetic field strength, the higher the resolution and the more sensitive the NMR spectrometer. The first commercial instruments, which used permanent magnets, were limited to excitation frequencies of 100 megahertz. Superconducting magnets, introduced in 1964, now permit the use of excitation frequencies of 500 megahertz for experimental instruments.

Experiments at the Francis Bitter National Magnet Laboratory's High Field NMR Facility at the Massachusetts Institute of Technology use a 500-megahertz spectrometer to study regulatory proteins that turn genes on and off by binding to specific DNA sequences. Their target is the gene activity of a bacterium-infecting virus, or bacteriophage. "We know the DNA base-pair sequences, the amino-acid sequences, and the crystal structure of the proteins," explains Leo J. Neuringer, director of the facility. What he and his colleagues want to find out is how the proteins recognize specific DNA sequences among a million other base pairs in a cell. They also want to learn the structure of the protein-DNA interaction.

Researchers at the Bitter Laboratory are constructing a 600-megahertz spectrometer and are thinking about 750 meghertz and 1,000 megahertz instruments. Other experimenters reach for structural information in the opposite direction with a technique called zero-field NMR. Spectra are produced in the absence of an external magnetic field by directly measuring the effect of the field created by each atom's nuclear spin on the spin of nearby atoms. This technique yields information about couplings between atoms and about interatomic distances and extends NMR spectrometry to polycrystalline and amorphous solids.

NMR is sometimes used with another spectroscopy technique that analyses the resonance of unpaired electrons called electron spin resonance (ESR) spectroscopy. This technique yields information about the distribution and environment of electrons in a molecule, enabling researchers to better understand the electronic structure and dynamics of inorganic compounds and biological systems. These systems and compounds must have unpaired or free electrons for the technique to work because the resonances of paired electrons cancel each other. This requirement is fulfilled by a wide range of materials including natural and synthetic organic free radicals, transition metals from iron to gold, coal, oil shale, and metalloenzymes. Such materials are classified as paramagnetic, so the method also is called electron paramagnetic resonance (EPR) spectroscopy.

ESR uses higher frequency or energy than NMR. Samples are placed in a magnetic field and bathed in microwaves which have frequencies in the 1- to 70-gigahertz (billions of hertz) range. The microwaves induce transitions between the energy levels of the unpaired electrons. Absorption of the energy as a function of the magnetic field produces a spectrum that contains information about the structure and symmetry of the environment of the electrons.

Like NMR, ESR is used to follow chemical and biological reactions and to probe intermediates in such reactions. It is applied in studies of materials damaged by heat, fracture, or radiation, such as tissues damaged by x or gamma radiation. Synthetic organic-free radicals, called nitroxyls, are employed as labels or probes in biological systems. As such, their spectra reveal how cells change as a result of changes in external stimuli such as variations in acidity. Thus, they can be used to study cell respiration and to study how the function of a cell changes during division. When used in combination with NMR, ESR provides high sensitivity and NMR high resolution of hyperfine details of certain organic and inorganic systems.

These techniques and instruments have not only followed advances in basic science, but they have also made basic advances possible by enabling scientists to "see" faster, smaller, deeper, farther, and clearer. Fundamental science, instrumentation, and applied technology form a loop around which creativity travels in both directions. "It may once have been fashionable to see the creative process as beginning only after the instruments were in place," comments Graham Cooks. "No more. In spectroscopy, as elsewhere, the creative process is now clearly exercised in the development of improved instrumentation. To a considerable degree, science is informed observation and the quality of our science is limited by the power of our instruments of observation. Using previously neglected physical principles, combining apparently incompatible devices, setting mechanical, electrical and data-handling standards which go beyond state-of-the-art, and aiming all this at significant problems, is in itself high-quality science."

LASERS

Lasers provide a dramatic demonstration of how basic research leads to advanced technology which, in turn, makes possible new kinds of fundamental experiments and commercial applications. When they first proposed the idea of *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation in 1958, U.S. physicists Charles H. Townes and Arthur L. Schawlow were mainly concerned with pushing back the frontier of the possible. They wanted to extend the principle of masers, which amplify microwaves, to light amplification. In a maser, atoms of a gas or solid are excited by radio waves of a particular frequency. A few of the atoms relax to a ground state by emitting energy that interacts with the majority of the excited atoms. The interaction stimulates emission of radiation with the same frequency as the radio waves that triggered the process, producing amplified beams of microwaves that are coherent,[1] virtually monochromatic (i.e., of nearly a single frequency), and parallel or undirectional.

In 1960, Theodore H. Maiman built the first device that worked on this principle to produce an intense, monochromatic, unidirectional, coherent beam of light. Most people were not impressed with the achievement, and many referred to it as "a solution looking for a problem." C.T. Tang of Cornell University recalls "reading in a widely circulated trade journal, a well-reasoned and beautifully written article which argued eloquently and convincingly that lasers were merely an interesting scientific gadget and would have no technological impact." This view has looked more and more shortsighted each year since 1960, as lasers have been eagerly applied in diverse fields such as communications, manufacturing, medicine, and military operations. By now lasers have become the basis of a pervasive technology that has replaced older technologies in some areas, is making possible the previously impossible in others, and is opening up completely new areas of research and commerce.

Applications in Chemistry

In chemistry, for example, lasers have gone from the unique to the ubiquitous. "Lasers have spectacularly expanded our experimental horizons," states the *Report of the Research Briefing Panel on Selected Opportunities in Chemistry* prepared by the National Academy of Sciences/National Research Council. The narrow, powerful beams of light permit experimenters to "see" individual atoms, unravel the structure of molecules, and investigate the details of interactions that transform one compound into another. Unimaginably short pulses of laser light permit probing of reactions that occur in less than a millionth of a second down to times a billion-fold shorter—a femtosecond or 10^{-15} second. The photons, or units of light emitted by pulsed lasers, all have nearly the same frequency, providing an extremely sensitive and selective means of detection and analysis. Continuous or pulsed lasers of high power can selectively dissociate molecules or excite them to ordinarily inaccessible states of reactivity.

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[1] In a coherent source of light, emission of radiation by individual atoms bear a specific relationship to one another—in contrast to the usual, incoherent sources in which individual atoms radiate at random.

"Recent experiments indicate that analysts can expect to attain, in a number of cases, the ultimate limit of single-atom or single-molecule detection using laser-based methods," declares Richard N. Zare of Stanford University. These methods include laser-induced fluorescence and multiphoton ionization. In fluorimetry, a laser irradiates a molecule or atom with a specific frequency of light selected to excite the constituents of the sample to a higher energy state. Molecules or atoms that fluoresce emit photons as they relax to an unexcited state. The frequency of this emission is a signature that identifies the source and yields information about its internal state.

In multiphoton ionization, an atom or molecule absorbs more than one photon, which causes ejection of an electron. The target species can be detected and identified by measuring the positive or negative ions. The choice of ionization wave-length gives this technique its flexibility, and the availability of powerful lasers tunable over a range of frequencies makes multiphoton ionization a nearly universal detector.

Surface Chemistry. Both techniques are used to study the microchemistry of surfaces, a prerequisite for understanding such practical processes as catalysis, adhesion, and corrosion. Molecules can be released from a surface exposed in a high vacuum to a laser beam or other directed energy source. Such experiments investigate "the rates at which molecules 'walk' around on surfaces at various temperatures, what energy states they are in, and how to drive them from the surface," explains Zare. "This, in turn, permits us to understand phenomena such as how gases and liquids interact with solid particles and surfaces."

"Because of the unsatisfied bonding capability of the atoms at the surface, chemistry here is very different from that of the same reactants brought together in solution or the gas phase," comments the Panel on Selected Opportunities in Chemistry. "When chemists can 'see' what molecular structures are on the surface, then all of our knowledge of reactions in conventional settings becomes applicable. This will open the door to understanding and controlling chemistry in this surface domain." The panel emphasized the impact that this would have on development of heterogeneous catalysts—solid materials with large surface areas upon which reactions occur at high rate and selectivity. They find use in a large number of important industrial processes, such as petroleum refining, production of ammonia, and manufacture of nitric acid, and also form the active element in catalytic converters installed on motor vehicles. Researchers are also attempting to develop similar catalysts to remove sulfur oxides from smokestacks, to purify water, and to prevent acid rain.

Investigating Other Chemical Domains. Other researchers apply laser fluorimetry and multiphoton ionization to the detection of impurities present in part-per-billion, or part-per-trillion ranges. Zare and his colleagues used laser-induced fluorescence to detect 700 femtograms (700×10^{-15} gram) of a toxin that contaminates wheat. Multiphoton ionization techniques are applied to detect trace impurities that alter the electrical properties of semiconductor crystals.

This work requires ultrashort laser pulses when the lifetime of the fluorescing molecules or ions is disappearingly short. Researchers at the Massachusetts Institute of Technology have succeeded in producing a 16-femtosecond laser pulse, breaking the previous record of 30 femtoseconds held by scientists at AT&T Bell Laboratories. The latter researchers pursue such technology because it provides the only way to measure internal processes in superfast integrated-circuit devices. These processes include energy transfer, a subject of vital interest to chemists seeking to learn which energy states are most likely to lead to chemical reactions.

"With lasers tuned to the proper frequencies, it becomes possible to selectively excite different internal states," comments Stephen R. Leone of the National Bureau of Standards. We then can interrogate or probe the products of that excitation with a second laser to determine the influence that each vibrational, rotational, and electronic state has on reactive events." Product or transition states can be probed by laser-induced fluorescence or multiphoton ionization. Molecules that do not fluoresce can be characterized by their vibrational spectra, a technique known as Raman spectroscopy.

Controlling Chemical Reactions. The availability of powerful lasers with precise frequency outputs has led researchers to attempt the giant step from studying what happens in chemical reactions to controlling these reactions. If lasers can excite specific vibrational modes, it should be possible to break chemical bonds and selectively determine in advance the products of reactions. In conventional chemistry, heat excites all vibrational states of the reactants, and the chemist must accept the products and yields that nature provides. If laser "scissors" can be used to custom-tailor chemical reactions, even the word "revolutionize" would be too weak to characterize the impact of the results.

This prospect set many chemists to work with lasers on projects to create new materials with special properties. They quickly found, however, that the energy of a specific laser-excited vibration rapidly drains away into all the other vibrational modes. In other words, the energy focused at breaking a specific bond quickly becomes redistributed among all the bonds in a molecule, so that the laser simply serves as an expensive Bunsen burner.

Scientists now are working on various ways to overcome this problem. One approach is to quickly deposit enough energy into molecules that have vibrational modes that do not readily transfer their energy to other bonds. Another approach is to employ lasers to excite intermediate or transition stages of reacting molecules in such a way that they preferentially form the desired products. Enough progress has been made with such experiments to offer the hope that laser-controlled chemistry will someday be possible in special circumstances.

These circumstances would include production of limited quantities of expensive chemicals, including rare isotopes. The Department of Energy, in fact, has decided to build a pilot plant for the separation of fissionable uranium-235 from uranium-238 by a laser process. The method is expected to be more efficient and less costly than the presently used gaseous diffusion technique.

The difference in the number of neutrons in the nuclei of isotopes of the same element produces a difference in the frequency of laser light that each absorbs. To separate them, chemists employ a laser that emits the precise frequency of the isotope wanted. The pilot uranium-separation plant, to be built at the Oak Ridge National Laboratory in Tennessee, will use visible-wavelength radiation that is absorbed by uranium-235 but not uranium-238.

Other cases in which commerical laser chemistry may be practical include reactions involving solid-surface catalysis, and chain reactions in which a laser initiates the reaction but does not provide the energy to keep it going. As an example of the latter, chemists at Exxon Research and Engineering Company increased production of cumene hyperoxide, a starting material for acetone and other industrial chemicals, with the help of ultraviolet laser radiation.

The Next Laser Generation

The potential use of light to initiate, guide, and drive chemical reactions will be enhanced by new and improved types of lasers now becoming available or in the planning stage. For example, a highly specialized use of lasers is for pellet implosion in inertial confinement fusion. Advanced lasers also promise increased capabilities in a wide variety of other scientific, engineering, and industrial applications. Solid-state and semiconductor lasers are a case in point. Until recently, lasers made of a crystal or glass produced short bursts of power only at one wavelength. For example, a ruby laser, the kind built by Maiman in 1960, radiates at 694 nanometers (i.e., 10^{-9} meters—a deep red light). Newer classes of lasers made of alexandrite and alkali-halide crystals provide tunability over a range from 700 to about 3,300 nanometers. Alkali-halide devices comprise important sources of tunable radiation in the deep red and near infrared portions of the spectrum.

Semi-Conductor Diode Lasers. More efficient generation of coherent radiation at these wavelengths can be obtained with semiconductor diode lasers. However, increased efficiency is bought at the cost of relatively low power output. Optical damage to the reflecting surfaces and cooling problems impose average output limits of a few tens of milliwatts compared to 100 watts or more with alexandrite lasers. To increase power levels, researchers at Xerox Corporation have developed a method of coupling diode lasers into an array which emits radiation as a single laser. They report getting an average output at 832 nanometers in laboratory experiments.

A new type of semiconductor diode laser developed in 1982 radiates one watt of deep red light continuously by taking advantage of the so-called quantum well effect. Commonly made of sandwiches of gallium arsenide and aluminum mixed with gallium, such devices may be only 250 micrometers square and one micrometer thick. When an electric current flows across the laser, electrons fall into holes in the sandwich-filling or active middle layer, giving up energy in the form of photons. These photons all possess the same energy and frequency; they encourage electrons in the gallium arsenide to fall into other holes, emitting more and more photons of the same frequency. When the input current exceeds 0.3 ampere, the device begins to emit coherent radiation. As the current increases, so does the laser output.

Low excitation current, small size, ease of modulation, and long operating lifetimes make diode lasers and laser arrays strong candidates for applications such as three-dimensional vision and proximity sensors for robots, line-of-sight data transmission including satellite-to-satellite communications, fiber optic communications, and signal processing. Messages impressed on laser beams now are carried on glass fibers as thin as human hair. Such systems require conversion of electronic signals to light and then back to electronic signals. If all the information was in the form of light signals, the processing could be done a thousand times faster.

Experiments to date show that alternating layers of gallium arsenide-based semiconductors are good candidates for the optical analog of transistors. Scientists at AT&T Bell Laboratories and the University of Arizona work with a semiconductor sandwich of partially reflecting mirrors above and below a very thin layer of optically bistable material. A light beam sent into such material can be made to come out in either large or small amounts by changing the index of refraction of the material. Constructed as a switch, for example, the device would be "off" when the intensity of an incoming laser beam, called a holding beam, causes light to be trapped by the bistable layer. A second beam can alter the intensity of the holding beam such that the refractive index of the layer changes enough to allow the light to pass. In this situation, the switch would be "on."

In recent experiments at the University of Arizona, Hyatt M. Gibbs and Nassar Peyghambarian succeeded in turning on and off this type of optical switch using a diode laser about the size of a period on this page. Their goal is to develop a switch that can be turned on or off in one picosecond or less. Such optical devices would make higher-speed digital computers and signal processors and wide-bandwidth digital communications systems possible.

Free Electron Lasers. The modest power output and tunability of diode lasers could be vastly exceeded with free electron lasers. Still in the experimental stage, these devices promise tuning capability from far infrared to far ultraviolet wavelengths. (A single device cannot cover the entire range.) They also would be the world's most powerful lasers, emitting bursts of radiation energetic enough to trigger fusion reactions or to be the ammunition for directed energy weapons.

Whereas conventional lasers amplify light radiating from electrons dropping between excited and ground states in atoms or molecules, these devices tap the energy of free electrons moving through a magnetic field at velocities approaching the speed of light. Such electrons lose energy in the form of radiation with frequencies ranging from far infrared to x-ray. The loss, a handicap to some physicists because it slows the charged particles they are attempting to accelerate, is a boon to others who have discovered how to turn it into a source of coherent radiation: an electron beam is passed through an alternating magnetic field arranged to wiggle the beam or cause it to move with a wavelike motion. The wiggling accelerates the electrons and causes them to emit electromagnetic radiation. The wavelength of this radiation can be controlled by the spacing of the wiggler magnets and the energy of the electrons. The higher the energy and the smaller the spacing, the shorter the wavelength.

The output of the first free electron lasers, built in the late 1970's, was small compared with the input power of the electron beam. Improvements in design have resulted in a steady increase in efficiency. Researchers at the Naval Research Laboratory constructed a laser that produces 4-millimeter radiation bursts with a peak power of up to 75 megawatts at an efficiency of 6 percent. Researchers at the Massachusetts Institute of Technology, sacrificing power for 12 percent efficiency, produced 0.5 microsecond bursts of 1.6 to 4.2-centimeter radiation at 100 kilowatts.

Research teams at Lawrence Livermore National Laboratory, Lawrence Berkeley Laboratory, and at Los Alamos National Laboratory also work on high-power infrared free electron lasers. The former group boosted a 23 kilowatt beam from Livermore's Experimental Test Accelerator to 80 megawatts of coherent millimeter-wave radiation. This group plans to use the more energetic Advanced Test Accelerator to stimulate an infrared (10 micrometer) free electron laser. Others are exploring the possibility of constructing free electron lasers that emit radiation at visible and ultraviolet wavelengths. "It seems likely that such lasers will be best suited to applications that put a premium on efficient generation of large amounts of optical power with less emphasis on physical size, since compact, very high energy electron accelerators will be difficult to construct," comments C. Paul Christensen, president of Potomac Photonics in Alexandria, Virginia. "Although initial results are encouraging, a great deal of research remains to be done before the utility of free electron lasers can be adequately assessed."

Other Experimental Devices. In the meantime, researchers work to improve and develop other types of lasers capable of efficiently generating powerful ultraviolet and x-ray beams. Excitation of various rare gas-halogen mixtures with an electron beam or electric discharge produces ultraviolet photons. Commercial models of these excimer lasers are available with average power levels in excess of 100 watts for such applications as photochemical surface processing, selected chemical synthesis, and purification. Experimental systems capable of one kilowatt average output are under development. Pulse energies from these devices, of course, would be much higher. Scientists at Los Alamos National Laboratory used a krypton-fluoride excimer laser to obtain a pulse energy of 3,000 joules (one joule per second equals one watt). Their goal is to upgrade pulse energies to the point where the laser can trigger fusion reactions.

No commercial x-ray lasers are available yet, but laboratory devices have been constructed. Researchers at Lawrence Livermore National Laboratory generated "soft" x-rays from the hot, vaporized gases of yttrium and selenium which produced a wavelength of 15.5 nanometers. Economic and reliable x-ray lasers promise important applications such as smaller integrated circuit chips, three-dimensional holograms of biological structures, and measurements now difficult or impossible to make.

Measurement of Fundamental Standards

The virtually pure frequency of laser radiation is ideal for accurate measurement of length and time; the higher the frequency, the greater the accuracy. Experimenters have measured changes of length as small as one-hundredth of the diameter of an atom with laser radiation. Precise counting of the unvarying cycles of such radiation is the most accurate way of keeping time. The completion in the mid-1950's, of the first maser (the microwave predecessor of the laser) made possible clocks with a precision of one in a billion seconds, or one second in more than 30 years. Counting cycles of radiation from a cesium maser raised the accuracy to one part in 20 billion. Today, coherent emissions from stimulated hydrogen gas permit an accuracy of one part in 100 trillion, or one second in more than 3 million years.

Such measurements are used to obtain a more accurate definition of length. With the help of visible wavelength lasers, scientists from the U.S. National Bureau of Standards and the Canadian National Research Council have measured the frequency of yellow light from a laser at 520 terahertz (trillion cycles per second) and the frequency of red light from another laser emitting at 473 terahertz. The measurements were referenced to the fundamental standard of time and frequency—the so-called "atomic clock" which is based on a natural frequency of vibration in the cesium atom. The latter is the most precise physical standard available, accurate to one second in more than 300,000 years.

Once frequency is known, wavelength (distance) can be calculated by dividing frequency into the speed of light (299,792,458 meters per second). This method defines the meter as the distance traveled by light in a vacuum during 1/299,792,458 second. The nations of the world adopted this definition in 1983.

From 1960 to 1983, standard-makers defined the meter as 1,650,763.73 wavelengths of orange-red light emitted from a krypton-86 lamp. This definition is accurate to a few parts in a billion, but scientists are able to make measurements that exceed this accuracy. The new definition, more than ten thousand times (one part in ten trillion) more accurate, establishes a more precise ruler for scientists who measure planetary distances in light years or atomic distances in ten-billionths of a meter.

The quest for more precision has not ended, of course. Scientists want to improve the standard for time, which is the reciprocal of frequency. The atomic clock is based on the radio frequency absorbed or emitted when the cesium-133 atom makes a transition between two internal states. Because light represents a higher frequency than radio waves, an optical standard would be more accurate. Advances in laser technology promise to make this higher standard possible.

A much-sought improvement would be laser light that is completely monochromatic. The best lasers now made emit light with a frequency spread of about 100 hertz. Researchers like Theodor Hansch of Stanford University are trying to reduce this by a factor of one thousand. With such lasers, Hansch hopes to stop the random natural movement of a hydrogen atom to test the laws that explain how atoms absorb and emit light energy. Because of the Doppler effect, atoms coming toward an observer appear to absorb and emit light at a higher frequency than atoms at rest. The reverse occurs with atoms moving away from an observer. Hansch expects to use laser-generated photons coming from opposite directions so that the Doppler shifts cancel each other. "By making better lasers and stopping the motion of the hydrogen atom, we hope to reach a one-hundred-million-fold improvement in measurements of the spectra of light absorbed by atoms," Hansch explains.

To date, his measurements agree with the theory of quantum mechanics that predicts which frequencies will be absorbed. "We may confirm that the theory is correct, or we might find a surprise," he says. "Whenever technology makes possible new types of experiments like this, there are unexpected results." Such unexpected results increase our understanding of the universe.

Commercial Applications

Evaluating fundamental constants of nature is a recent application of lasers, but commercial systems for precise alignment and ranging have been available for two decades. As the sophistication of laser-based instrumentation increased, the technology was also applied to characterize and identify unknown materials. Chemistry exemplifies this, as does the area of remote sensing where lasers now facilitate investigation of the size, distance, and composition of a variety of particles and gases which may be located tens of kilometers from the sensing instruments.

Remote Sensing. The basic arrangement for remote sensing mimics that for radar (*ra*dio *d*etection *a*nd *r*anging). Fixed-frequency light pulses illuminate distant objects, which scatter the light back to sensitive receivers. The time delay and frequency shift of the return signal contain information about the range and velocity of the target. Such laser radar or lidar (*li*ght *d*etection *a*nd *r*anging) can also be employed to obtain spectroscopic information about the composition of particles and gases.

Single-wavelength lidar is used to study atmospheric aerosols in the same way that radar provides information about rain. Investigators at Stanford University used lidar to trace volcanic dust from the 1982 eruption of El Chichon in Mexico as it spread around the Earth in tropical latitudes. University of Illinois researchers applied it to obtain vertical profiles of dust clouds from Mt. St. Helens and to study the effects of wind streams on these clouds. Airborne lidar systems rapidly measure coastal-water depths, utilizing the time difference between reflections from the surface and scattering from the sea floor. Other single-wavelength equipment has been used for applications that include pollutant detection and aircraft collision avoidance.

Multiple-wavelength systems sense a variety of atmospheric gases including sulfur dioxide, nitric acid, and carbon dioxide, via a differential absorption technique. One wavelength, tuned for minimal absorption, serves as a reference signal; the other is tuned to the absorbing transitions of the target molecules. Differential absorption lidar (DIAL) provides data about both density and composition. As with other lidar systems, range and sensitivity are a function of the energy of the laser pulse. Ranges of several tens of kilometers and sensitivities exceeding one part in a million are common.

Robert Byer and his colleagues at Stanford developed a tunable infrared lidar for simultaneous measurement of temperature and humidity. Two wavelengths measure the density and vibrational-rotational states of water molecules; a third generates the reference signal. Temperature data comes from the vibrational-rotational states which are a function of temperature. Other systems sense particles by means of the scattering of infrared radiation. Each material has a distinct scattering signature; even different concentrations of sulfuric acid in water droplets produce characteristic returns. Differential scatter (DISC) systems can distinguish between clouds containing harmless ice and those containing supercooled water which can cause ice buildup on aircraft.

Improvements in laser power and tunability promise to increase the range and selectivity of DIAL and DISC systems. In addition, the two eventually will be combined into a single device for sensing both particles and gases. A significant improvement in tunability is needed to easily map the broad absorption and reflection spectra of liquids and solids. Laser fluorimetry has been applied to remote sensing of trace constituents in the upper atmosphere and to detection of algae, oil spills, and other water pollutants. Ultimately, laser remote sensing will be extended to rapid mapping of extensive land and ocean areas from aircraft and spacecraft. "Using only a few people and suitably equipped airplanes, the entire surface of the United States can be monitored," notes Byer.

Biomedical Applications

The narrow, powerful beams of light that make lasers well-suited to sense remote gases and particles also serve, at close range, for cutting, drilling, and welding everything from metals to human tissues. Physicians utilize lasers for applications ranging from eye surgery and vaporizing tumors to removing warts and tattoos. High-powered lasers coupled to microscopes produce focused microbeams as small as 0.1 micron (millionth of a meter) in diameter. Such beams can destroy previously inoperable tumors on the brain stem. In research experiments, these microbeams selectively ablate groups of cells, single cells, or even subcellular structures, such as chromosomes, to determine their function or investigate their response to trauma.

Guenter W. Gross and his colleagues at Texas Woman's University study the effects of central-nervous-system trauma on single cells. They cut lesions as minute as 0.7 micron in mouse cells with a pulsed ultraviolet laser. The cells are monitored through the same microscope that is used for the laser knife, as well as by electrophysiological recordings of the cellular reaction before and after injury. A major objective is to assess the regenerative potential of the neurons. This model is believed to mimic what occurs in humans who suffer head and spinal cord injuries. "Limitations of existing techniques have forced investigators of such injuries to focus primarily on damage at the organ and tissue level," Gross points out. "Laser microbeam studies should enable us to obtain an adequate understanding of the mechanisms underlying cell reactions."

Such microprobes also play a key role in an innovative technique to investigate signal processing and storage in neuronal networks. The standard procedure of using microelectrodes to probe networks of nerve cells and their interconnecting fibers often damages the circuitry they attempt to monitor. To avoid this, researchers create artificial, two-dimensional networks on which cells are grown in culture.

Researchers at the Laboratory of Molecular Biology in Cambridge, England, have utilized laser microbeams in a brilliantly conceived and extremely difficult effort to obtain the first complete description of the whole nervous system of a multicellular animal. They labored for more than a decade to map all the neurons and connections in the 1-millimeter-long roundworm *Caenorhabditis elegans.* In addition, they followed the development of the worm's nervous system from the egg stage to mature adulthood. During the process, destruction of individual cells and blocking migration of neuron precursors by laser ablation enabled the researchers to correlate specific neurons and reflex circuits with particular behaviors, as well as to determine how disruption of cellular interactions affects neuronal development.

The Future

The emerging applications of lasers in neuroscience studies, measurement, remote sensing, and chemistry represent only a sampling of the potential of this technology. Advances in output power, tunability, stability, and frequency resolution will continue to expand the horizon of usability. For example, researchers are extending the range of laser radiation to extreme ultraviolet and x-ray frequencies. Lasers that stimulate emissions from electrons instead of gases, liquids or solids, promise tunability from infrared to ultraviolet frequencies in a single device. Experimental free-electron lasers connected to accelerator storage rings convert electrons with enormous energy into the prototypes of the world's most powerful lasers. Integration of lasers with instruments such as mass spectrometers, and steady improvements in these instruments, will contribute to the expansion of this technology. As these laser systems evolve, they will make it possible to transform established concepts into experimental and practical reality. Also, as more researchers are exposed to easy-to-use lasers, they will develop new concepts to increase our understanding and commerce.

SUPERCONDUCTIVITY

The synergy of technologies, as well as instruments, is increasing our understanding of the fundamentals of nature and making practical applications of this understanding possible. For example, improvements in Fourier transform mass spectroscopy and nuclear magnetic resonance imaging are directly tied to advances in superconductivity technology. Superconductivity, in turn, has progressed from an object of basic research to an emerging technology largely because of advances in materials science and metallurgy.

While scientists still puzzle over how it works, the conduction of electric current without resistance promises to save researchers millions of dollars a year in power costs. It is making higher-energy particle accelerators, ultrasensitive detectors and measuring instruments, and higher-resolution, safer imaging for medical diagnosis practical. For the future, it promises a new generation of supercomputers; vast improvements in generation, transmission and storage of electricity; advanced circuitry for high-speed signal processing; and the harnessing of fusion energy. Malcolm Beasley of Stanford University refers to superconductivity as "a science turning into a technology." He believes that ongoing developmental efforts in this field "will have their day in the 'court' of the real world in the coming decade."

The Fundamental Process

Superconductivity was discovered in 1911 when the Dutch physicist Heike Kammerlingh Onnes found that resistance to electric current in a mercury conductor suddenly vanished when he cooled it to a temperature of about 4 degrees above absolute zero (4 degrees Kelvin). John Bardeen, Leon N. Cooper, and J. Robert Schrieffer shared a Nobel prize in 1972 for their 1957 theory explaining how normal conductors become superconductors. According to this theory, when conductors are cooled to temperatures near absolute zero, electrons travel rapidly through the metal's lattice structure, attracting positive ions as they go. Atoms and molecules possess the minimum possible energy at absolute zero—zero degrees Kelvin—or minus 273 degrees Celsius. Under the right conditions, a circulating current is formed that has persistence against decay. These conditions involve a delicate balance between temperature, magnetic field strength, and current density. When the balance is achieved, current flows endlessly without additional power and with a negligible loss of energy. Such currents sustain intense and steady magnetic fields which make instruments for detection, measurement, and medical diagnosis possible.

Superconductors can be defined by the transition temperature at which they switch to a non-resistive state, the strength of a magnetic field in which the material ceases to superconduct, or the maximum current that the material can carry. The highest possible transition temperature is desirable to keep down cooling costs. A high critical current becomes important in the case of long-distance power transmission. High field strength is required for large magnets used in particle accelerators and fusion reactors to keep the machines small and efficient.

The Search For New Superconductors

Since high transition temperatures are desirable for every application, this factor dominates discussions of superconductors. Progress in raising the temperature from 4.2 degrees Kelvin, the boiling point of liquid-helium refrigerants, has been slow and frustrating since 1911. By switching from single elements (such as mercury, lead, niobium, and tin) to alloys, researchers raised the critical temperature to 18 degrees by 1954. Another 30 years of intensive effort has added less than 6 degrees. In 1973, scientists discovered that a niobium-germanium alloy goes into a superconducting state at 23.2 degrees, which remains the upper limit.

A worldwide effort exists to find material that will superconduct at higher temperatures. A compound that makes the transition at 30 degrees, for example, could be cooled with liquid hydrogen. This more-effective refrigerant is cheaper and more abundant than increasingly scarce and expensive liquid helium, although it is more dangerous. Temperatures of 80 degrees and higher would permit the use of liquid nitrogen, inexpensive and plentiful enough to make superconducting electric transmission lines a reality. Some scientists predict that it may even be possible to make materials that would be superconductors at room temperatures.

Lack of fundamental knowledge hampers the drive to higher temperatures. "We don't know why niobium is a magic metal," confesses John Hulm of the Westinghouse Electric Corporation's research center in Pittsburgh. "We don't even know why niobium-germanium has a critical temperature of 23 degrees or why it is so sensitive to the method of fabrication." Physicists cannot easily narrow the search for new materials because they cannot predict which ones will superconduct.

To date, niobium alloys have been the workhorses of superconducting technology, with transition temperatures ranging from 9 degrees for niobium-titanium to 23 degrees for niobium germanium. The next compound in this sequence, niobium-silicon, could theoretically attain a critical temperature of about 35 degrees, but this has proved difficult to achieve. Even with the help of heroic fabrication measures, such as explosive compression, no one has been able to coax this compound to superconduct above 18 degrees.

This difficulty has steered researchers to other materials, including three-compound superconductors such as rare-earth elements combined with rhodium and boron, and molybdenum sulfide combined with a metal or rare earth. Researchers at the Francis Bitter National Magnet Laboratory, Massachusetts Institute of Technology, have experimented with a lead-molybdenum-sulfur compound, and report transition temperatures of 15 degrees and a higher critical magnetic field than obtainable with most other materials.

Organic Superconductors. In 1980, Dennis Jerome of the University of Paris-South at Orsay made the first observation of superconductivity in a synthetic organic compound. Known as TMTSF, the material is a complex crystal containing selenium, carbon, phosphorous and fluorine. At first, TMTSF showed non-resistance only under high pressure. Scientists believe that the pressure squeezes the crystal until conducting selenium atoms reach the right distance apart and possess the right orientation for superconductivity. Investigators at Argonne National Laboratory, near Chicago, experimented with similar compounds and found that this transition occurs naturally in TMTSF-perchlorate at atmospheric pressure when the salt is cooled slowly to one degree Kelvin. Scientists at Argonne and other laboratories now are preparing other TMTSF salts in an attempt to find compounds with higher transition temperatures.

IBM scientists discovered a second class of organic superconductors in 1982. Known as BEDT-TTF compounds, they can be made with many chemical and structural variations. One of these compounds, the only known sulfur-based organic material known to be superconducting, becomes superconducting at 2 degrees under 4,000 times atmospheric pressure. Twenty years ago, William A. Little of Stanford University proposed a hypothetical mechanism that could produce an organic molecule that would superconduct at room temperatures. The effort to find or make such a molecule continues.

Probing the Limits. To be used in superconducting magnets, such materials should ideally be fabricable as wires. However, this has proven difficult, because niobium-germanium cannot be drawn out into wires. Niobium-tin produces strong magnetic fields but it is brittle and expensive. Niobium-titanium, which dominates superconducting applications, offers ductility and reasonable cost, but its technical performance is limited.

Most superconducting devices in electronic circuits, such as those used in instruments and in work on superconducting computers, consist of a thin sandwich of electrodes separated by an insulator only a few nanometers (billionths of a meter) thick. For such devices, "the most important synthesis technique in the near future is clearly thin-film synthesis based on vapor deposition," according to *Research Opportunities in Superconductivity*, a 1983 report prepared by the National Science Foundation and the Office of Naval Research. "The power and relevance of this approach for superconducting materials research and development have already been demonstrated."

Researchers at the National Magnet Laboratory use thin films to probe the basic limits of superconductivity and the structure of matter. Why, for example, does niobium-tin sustain higher magnetic fields than predicted by theory? The theory assumes that electrons move freely through a metal, but we find that this does not hold for many materials in very high magnetic fields," answers Robert H. Meservey. "In this situation, electrons interact with each other through their spin properties or magnetic moments, and that apparently changes a material in such a way as to increase the upper limit of the critical field." Meservey and his colleagues work with thin films of vanadium gallinide which sustain fields as high as 25 tesla. By changing the spin properties of this material via the addition of a third element, they expect to expand its capacity to 40 tesla. On a more fundamental level, measuring how electron interactions in ultrathin films change as a function of high magnetic fields provides a way to understand the nature and limits of superconductors.

Applications

The Josephson Junction. Such understanding is a prerequisite to improving and predicting the performance of material used in successful superconducting electronic devices such as the Josephson junction. The concept of its operation, originated in 1962 by Brian Josephson of Cambridge University, depends on the wave nature of electrons. Under proper conditions, electrons tunnel through a thin insulator. A voltage drop occurs in normal tunneling, but when the electrodes are superconducting no voltage drop takes place. A small current passing above the junction generates a magnetic field that switches the device from the superconducting to the normal state, or vice versa. This behavior provides a basis for circuits with potentially widespread scientific and commercial applications.

Using the thin-film approach, Josephson junctions are fabricated by depositing a base electrode, the insulator or tunneling barrier, and then the top or counterelectrode. Excellent junctions incorporating high transition-temperature base electrodes can be made, but high-temperature counterelectrodes are difficult to construct. The problem lies in forming a high-quality film at temperatures low enough not to damage the underlying barrier. The two most likely candidates for success are alloys with the same structure as niobium superconductors, and a compound of niobium and nitrogen. At present, the latter is more advanced because it can be deposited at low temperatures, sustains high magnetic fields, and becomes superconducting at relatively high temperatures.

Josephson junctions can be made very small. IBM engineers put more than 20,000 of them on a chip measuring less than 7 millimeters on a side. The devices can be packed to such densities because they generate so little heat. One experimental memory chip with about 45,000 junctions consumed a scant 10 millionths of a watt. Power consumption drops to zero for information storage since circulating currents encounter no resistance. Memory access times and logic-gate switching occur at speeds of picoseconds (trillionths of a second). Fast switching, dense packaging, and low energy requirements make Josephson junctions ideal components from which to construct compact, ultrahigh-speed computers—superconducting supercomputers.

Such a machine seems so attainable that even conservative scientists predicted softball-size supercomputers by

1990. However, IBM, the U.S. leader in producing Josephson junction logic and memory chips, abandoned the effort in September, 1983. The company experienced difficulties in fabricating junctions with the required current range. If the current is not kept within narrow limits, the junction will not superconduct because a voltage arises across the junction. IBM engineers believe that by the time this problem can be corrected, the speed of silicon or gallium arsenide semiconductors will be competitive with the performance of Josephson junctions.

The Japanese continue to pursue the goal of a superconducting supercomputers based on Josephson junctions, but the first such U.S. machine may be based on another device, such as a superconducting transistor. "New devices, particularly a three-terminal transistor like device, are certainly a *sine qua non* for another approach to a general purpose, high performance superconducting computer," note the authors of *Research Opportunities in Superconductivity*. Meanwhile, ultrafast computers probably will be constructed to operate at cryogenic temperatures higher than those needed for superconductivity but lower than 153 degrees Kelvin (minus 120 degrees Celsius).

IBM scientist Sadeg M. Faris invented a three-terminal superconducting device that both amplifies incoming signals and switches rapidly. Called a *quiteron*, it is a double-decker sandwich of three films of superconducting material separated by two thinner films of insulator. Quiterons boast switching speeds of less than 300 picoseconds and power dissipation about one-hundredth of the best semiconductor transitors. However, they have limitations, too, and do not appear to be the devices that will make superconducting supercomputers a reality in the next decade or two.

The advantages of Josephson junctions have not been overlooked for other applications. Particularly promising in the near future are systems built around fast analog-to-digital converters and other high-speed signal processing devices.

Superconducting Quantum Interference Devices. Scientists are also excited about the use of Josephson junctions for ultrasensitive instruments and detectors known as SQUIDs—superconducting quantum interference devices. Impressing a magnetic field on a junction causes the current at one point to have a different polarity from that at another point and thus to produce interference. In other words, the phase difference between electron waves reduces the current through the junction. The interference can be utilized to measure extremely weak magnetic fields and, thereby, minute voltages and currents. Voltmeters based on this effect detect potentials as small as a femtovolt (a millionth/billionth of a volt).

SQUIDs measure changes in the earth's magnetic field of one part in 10 billion, measurements that can be used for detecting mines and submarines at sea or ore deposits, and geothermal energy sources on land. One of the most widespread and exciting application of SQUIDs involves non-invasive techniques to diagnose brain abnormalities (magnetoencephalography) and heart malfunctions (magnetocardiography). Astrophysicists are anxious to apply SQUIDs to detection of far infrared (millimeter) wavelengths, a window to the sky that has been largely inaccessible. Other experimenters expect to use them for detection of gravity waves, and, possibly, the elusive monopole, theoretically the fundamental unit of magnetism.

The Quantum Hall Effect. As the area of a SQUID decreases, its operating frequency, and thus its sensitivity, increases. This provides another incentive to make devices smaller than one micron (millionth of a meter). Microminiaturization also equates with faster switching, reduced energy requirements, compact size, and circuits with new applications. As the limits of size are pushed smaller, the limits of temperature lower, and the limits of magnetic field strength higher, new regimes open up to both industrial and basic researchers. A dramatic example occurred in 1983 with the discovery of a previously unknown state of matter, made as a result of experiments with semiconductors at extremely low temperatures and very high magnetic fields.

Daniel C. Tsui of Princeton University, together with Horst L. Stormer and Arthur C. Gossard of Bell Laboratories, went to the National Magnet Laboratory to obtain the low temperatures and high fields needed to test their ideas about the quantum Hall effect. The effect dates back to 1879 when Edwin H. Hall discovered that a voltage or electric field is induced across a conductor (in this case, gold foil) carrying a current in a magnetic field perpendicular to the current direction. The electric field builds up at right angles to both the current flow and magnetic field, and its strength is proportional to the strengths of both. This effect caught the interest of modern scientists when West German and British physicists found that under certain conditions, the electric field increases in abrupt steps as the magnetic field increases. The interval between steps does not depend on the conducting material but is always a whole number multiple of the current times the square of the electron charge divided by Planck's constant. Tsui, Stormer, and Gossard examined this quantized Hall effect at temperatures below 2 degrees Kelvin and at magnetic fields as high as 28 teslas. In their experiments, the steps occurred at both integral multiples and fractions of integral multiples. The fractions have values such as 1/3, 2/3, 2/5, 3/5, 2/7, etc., in which the denominator is always odd.

The conductor in these situations is a thin layer at the surface of a semiconductor in which electrons move freely. The laws of quantum mechanics confine their motion to a plane parallel to the interface between semiconductor layers. In some of the experiments, for instance, electrons were contributed by impurities doped into an aluminum gallium arsenide crystal. Free to move only in the plane of an interface between this crystal and a gallium arsenide crystal, the electrons behaved like a two-dimensional gas. The concentration of these electrons was fixed by the concentrations of doping atoms, not by an external voltage. When the strong magnetic field was applied perpendicularly to the interface, it imposed discrete or quantized energy levels on the conducting electrons.

Electrons at particular energy levels orbit the magnetic field lines with a radius fixed by the field strength and the energy. The number of orbits, or quantum states, equals the number of field lines, and it increases linearly with field strength. As the strength increases, the Hall effect is quantized for those values of the field for which the number of orbits exactly matches the number of electrons.

Robert Laughlin of Lawrence Livermore National Laboratory has proposed that the fractional quantization results from interactions among the electrons. At very low temperatures and high magnetic fields, their motions are no longer weakly interactive as they are in an electron gas. Instead, they interact strongly and the resultant highly coordinated motions produce the fractional steps. This motion is characteristic of a liquid rather than a gas. There are no obvious applications for the newly discovered state of matter, but it initiates a fundamental change in scientific thinking.

Ultra High Field Magnets

Particle Accelerators. Superconductors, in addition to being involved in fundamental and applied experiments with some of the smallest devices used in science and engineering, are also part of experiments with the world's largest science machines. Superconducting magnets are vital components in the world's highest-energy particle accelerator. Operation of these machines becomes much less costly, because once the magnets are charged with current, the current and magnetic field persists with almost no further additional energy. Typically, the magnets lose only one ten-millionth of their field strength per hour, so that hundreds of years could pass before a field decays to one-half its starting value. Although energy must be expended to run the cryogenic (i.e., ultra-low temperature) refrigerators and to charge the magnets, superconducting systems are as much as 90 percent efficient. The Fermi National Accelerator Laboratory, near Chicago, cut the power consumption of its Tevatron accelerator by more than half and will double the machine's energy output with this technology.

Niobium-titanium is the dominant material for superconducting magnet coils. Thin filaments of it are embedded in copper because this arrangement speeds the field's recovery if the superconductor inadvertently reverts to a resistive mode. At higher-than-transition temperatures, copper has much less resistance than the niobium alloy, so in the non-superconducting state the copper provides a relatively low-resistance path for the current. Copper also is an efficient thermal conductor; it sheds enough heat to lower temperatures below the transition point, then the current shifts to the superconductor.

Operators of the Fermi Tevatron keep its 1,000 niobium-titanium superconducting magnets at approximately 4.6 degrees Kelvin with cryogenic fluids circulating in cryostats surrounding the coils. Each magnet, 3 meters long and weighing 2,700 kilograms, boasts a peak field of 5 tesla. This is approximately 100,000 times the strength of Earth's magnetic field, or 17 times that of the strongest electromagnets used for picking up scrap metal.

The ring of 1,000 superconducting magnets, called the Energy Saver, was installed in a 6.4-kilometer-circumference tunnel that houses a 400-billion-electron-volt (GeV) conventional accelerator, completed in 1972. The superconducting technology is expected to increase this accelerator's output to one trillion electron volts (TeV), making it the most energetic in the world. During a test in July, 1983, the machine achieved a record energy of 0.512 TeV. When up to capacity, protons will zip around the ring 50,000 times per second. They will reach an energy of 1 TeV and then slam into targets of atomic nuclei.

The Tevatron will probe even deeper into the nature of matter when researchers initiate a more advanced mode of operation—the Tevatron Collider. While protons circulate in one direction around the accelerator, an intense beam of antiprotons will be added, moving in the opposite direction. Both beams will collide after being accelerated to 1 TeV, releasing a total of 2 TeV of energy. This should provide insight into the most elementary forms of matter and how they are held together.

The Tevatron holds the distinction of being the world's first high-energy superconducting accelerator, but it is only the bottom step on the ladder of trillion-electron-volt atom smashers. In 1984, U.S. physicists submitted three designs to the Department of Energy for a superconducting supercollider (SSC) which would generate two colliding beams of 20 TeV each. One design would use relatively inexpensive 3-tesla magnets in a ring 164 kilometers in circumference, a second would feature 5-tesla magnets in a 113-kilometer ring, and the smallest would involve 6.5-tesla magnets in a 90-kilometer ring. This latter ring would have a circumference about the size of Washington, D.C.'s Capital Beltway.

Five tesla magnets already exist, but a 6.5 tesla superconducting magnet has yet to be built. Such a device should be achievable by 1994, the earliest that the SSC could be completed.

In 1980, researchers at the National Magnet Laboratory completed the world's most powerful magnet, a 30-tesla hybrid of a superconducting part and a water-cooled part. "We get about 21 tesla from the water-cooled magnet and 9 tesla from the niobium-tin superconductor," explains Bruce Montgomergy. "In principle, you'd like to build the magnet all out of superconductor . . . but it becomes very expensive to generate a field above a certain level with superconducting material." Montgomery and his colleagues are studying the possibility of a pulsed, as opposed to steady field, magnet of 75 tesla. Such a device, he says, "would be of inestimable value to the high-field superconductivity and magnet-development communities. It would help unravel problems in many disciplines other than particle physics, such as the electronic structure of exotic metals, spectroscopy of atoms and molecules at high temperatures and high fields, and the study of biological systems using nuclear magnet resonance spectroscopy.

Whatever size magnets it uses, the SSC will cost at least $3 billion and perhaps twice as much. The high price has led European scientists to propose a $500 million alternative. Researchers at the European Laboratory for Particle Physics (CERN) suggest adding a ring of superconducting magnets to an existing machine to produce proton collisions of as much as 9 TeV on 9 TeV. However, this would require 10 tesla superconducting magnets which do not yet exist. Therefore, a cost as low as $500 million is debatable. However, a general consensus exists that wonderful discoveries await at 20 plus 20 TeV, things that would make the $3 billion price worthwhile. U.S. scientists have approached Japanese and European researchers with a proposal to help finance the construction and, failing that, the operation of the SSC and make it an international effort.

Thermonuclear Fusion. Magnets such as those used in the MSU cyclotron and the Tevatron are likely to be desirable for efficiently containing the hot, electrified gas or plasma required for thermonuclear fusion. The first successful controlled reactions probably will fuse ions of the hydrogen isotopes deuterium and tritium in a plasma at temperatures about 100,000,000 degrees Celsius. Experiments now underway use magnetic "bottles" (intense magnetic fields) to contain such infernal states of matter. These require enormous amounts of energy to generate and maintain. Superconducting magnets could cut these energy requirements sharply and contribute to realizing the long-sought goal of a fusion reactor that generates more energy than is needed to heat and confine the fuel.

Researchers at the Lawrence Livermore and Oak Ridge National Laboratories are attempting to control the hottest material ever made by man with his coldest technology. Those at Livermore's Magnetic Fusion Test Facility work with one of the world's largest magnets, a 341,000-kilogram superconductor with 50 kilometers of niobium-titanium wire. Ten thousand liters of liquid helium flowing at 6 liters per second cool the magnet. Even this river of refrigerant takes 11 days to reduce to operating temperature. However, one such superconducting enormity is not enough; eventually, the test machine will contain more than 20 such magnets.

Oak Ridge's large coil project involves experiments to confine the fiery plasma in a toroidal (doughnut-shaped) bottle made of six separate superconducting magnets. Scientists there asked six manufacturers to each design a different type of magnet. Tests will determine which design is best for a more advanced machine. Five of the six magnet-makers chose niobium-titanium for the coils; one opted for niobium-tin.

The Future

These activities and others demonstrate that superconductivity has progressed from a laboratory curiosity to a powerful scientific tool, from a science to a technology. The next step already being taken is to move the technology from the laboratory to the marketplace. The first commercial products, in use at several hospitals, are nuclear magnetic resonance imaging instruments. The magazine *High Technology* estimates that the market for NMR diagnostic machines will reach $600 million by 1990. It also forecasts a $225 million market by 1990 for superconducting electric generators. The first such machine, a 300-megawatt generator, is expected to be installed soon at the Tennessee Valley Authority's Gallatin Station in Tennessee.

Josephson junctions lie on the brink of commercial application for detection and measurement (as a component of improved SQUIDs), signal generation and processing, and analog-to-digital converters. Applications beyond 1990 will include superconducting computers, the first of which may be built by the Japanese. The technology also has a future in the business of transmission and storage of electric energy. Meanwhile, basic scientists continue to wonder and study why a technology with such a far-ranging potential works at all.

MONOCLONAL ANTIBODIES

No advance in the past decade has impacted biology and medicine more than monoclonal antibody technology. And, with the exception of gene splicing, none promises as much for the future. Developed in 1974, this technique makes possible the production of unlimited amounts of pure, uniform antibodies that bind to a specific molecule or cell. This makes them a powerful tool for the study of fundamental biological and genetic processes and for the diagnosis and treatment of many diseases, including cancer. "Combined with new instruments and other biotechnologies, monoclonal antibodies make an incredible difference in the kinds of experiments that we can do and in the speed at which we can do them," comments Leroy E. Hood of the California Institute of Technology. "And these experiments are producing, and will continue to produce, dramatic results." The results already are being applied to the diagnoses and treatment of a variety of diseases, including cancer. The advances made in clinical applications captured headlines and the public's imagination in 1984, but they represent only one area in which the less-publicized fundamental research is providing profound insight into the way that nature works.

Discovery of the Technology

Discovery of the monoclonal antibody technique occurred late one evening during the 1974 Christmas season in a windowless basement at the Medical Research Council's Laboratory of Molecular Biology in Cambridge, England. Cesar Milstein and Georges Kohler hit upon the idea of combining a lymphocyte, a type of white blood cell that secretes a highly specific antibody, with a rapidly replicating tumor cell. Antibody-secreting cells cannot be cultured, so they hoped that the hybrid would be able to do what had not been done before: generate inexhaustible quantities of cells that produce large amounts of pure antibody. Kohler admits they both thought that this was a "crazy" idea that would not work—but it did work. Kohler saw the first evidence of success on culture plates that evening. "It was fantastic," he recalled. "I shouted; I kissed my wife . . . . It was the best result that I could think of." The achievement earned Milstein and Kohler the 1984 Nobel Prize for Medicine.

The hybrids or hybridomas produced by monoclonal antibody technology can be grown in culture or injected into animals to produce the desired antibodies. The resulting clones are immortal in culture, and they can be frozen for long-term storage. This ability to produce probes that find specific molecules or cells in a mixture as complex as human blood ranks in significance with the capability to cut and splice genetic material in ways that might eliminate harmful genes or create combinations more beneficial than the natural set of hereditary instructions. Both open up possibilities for fundamental research that was once beyond reach or imagination. The medical applications that often follow such research offer the potential for relieving a significant amount of human suffering.

In the case of monoclonal antibodies, however, this potential was limited at first because the human immune system sees antibodies from mice as foreign tissue which it may destroy before any good can be done. Clearly, scientists had to extend the technique to produce human antibodies.

But production of human monoclonal antibodies turned out to be more difficult than anyone anticipated. It took more than five additional years of hard work, failure, and luck. A key player in the effort, the late Henry S. Kaplan, divided his time in 1979 between basic research and clinical medicine at Stanford. Lennart Olsson arrived there in 1979 to do postdoctoral work with Kaplan. "My habit with new postdocs," said Kaplan, "was to let them wander around for a couple of weeks to see what's going on. Olsson did this, then came to see me with a shopping list of possible projects, one of which was to take a crack at making human hybridomas."

A major problem was to find a line of tumor cells with which human lymphocytes could be fused. The solution sat in cold storage at Stanford's Cancer Biology Research Laboratory. Kaplan had put it there unknowingly after unsuccessful experiments involving the role of viruses in certain types of cancer. About 2 years before Olsson's arrival, Kaplan obtained the cells from humans who had died of myeloma or cancer of the bone marrow. When the cells reached Stanford from Sweden, they were in such poor condition that it required 4 months of careful work to bring them back to peak health. Kaplan then used them in his virus work, but "none of the experiments worked," he recalled.

As it happened, the cells were the same type that several research groups, including Milstein's, had been trying to use to make human hybridomas. This fortuitous circumstance provided Olsson with half of what he needed. The other half—the lymphocytes—had to come from human spleen cells.

Again, fortune stepped in. Kaplan was involved in treatment of patients with Hodgkin's disease, a cancer of the lymphatic system that often attacks the spleen. One aspect of treatment includes removal of the spleen. Before this occurs, however, physicians test a victim's immune system by exposing it to a substance known as 2,4-dinitrochlorobenzene. Most patients manufacture antibodies to a specific part of this compound, an antigen called dinitrophenol or DNP. Thus, Olsson had access to human spleens that had been immunized with a known antigen. "We simply took the next three patients who came along and used the spleens as a source of antibody-producing cells," Kaplan explained.

Human lymphocytes obtained in this way are predisposed to fuse with tumor cells because they are in a state of imminent proliferation; lymphocytes that do not fuse die in culture. The tumor cell line carries a specific mutation to allow the culture medium to select against its unfused portion. Some fused cells that survive produce the desired antibody; others make a variety of different antibodies. When investigators distribute a solution containing a mixture of these cells among many incubation wells, they hope that at least one well will contain only the hybridoma that they want.

This was a crucial stage for Kaplan and Olsson. "The whole process of making monoclonal antibodies was so complex, with so many places that it could fail, that I felt it was absolutely essential for it to work the first time," Kaplan declared. "Usually you don't feel that way about an experiment. If it doesn't work one way, you try it another way. With this, there were so many ways it could fail, that if it did fail we would not know what to change." Luck stayed with them. In March, 1980, after days of anxious waiting and testing, they isolated clones of cells that produced antibody to DNP from two of the three spleens.

Kaplan and Olsson were not the only scientists working toward the goal of human monoclonals, and they were not the only ones to succeed. In early 1980, Carlo Croce and his colleagues at Wistar Institute in Philadelphia obtained lymphocytes from the brain of a girl with a measles infection of the brain (subacute sclerosing panencephalitis). They fused these with cancer cells from a person who died of multiple myeloma. This gave them clones of human cells that made antibodies against the measles virus. Croce notes that "we now can get clones that produce antibodies against all sorts of human antigens."

Each antibody attacks or pairs with one of many antigens or distinctive molecules on the surface of a cell, virus, or bacteria. One antibody might bind to the specific antigen that marks a cell as a human blood cell, another with an antigen that indicates it is a human breast cell, and a third with an antigen marking the cell as cancerous. Milstein and his colleagues, for example, have produced a series of antibodies to rat-cell antigens that establish the identity of an individual and are responsible for rejection of grafts. These antigens serve as immunological fingerprints that distinguish "self" from foreign invaders such as viruses and cells from other organisms. The closer a donor's and recipient's fingerprints, the greater the possibility that a graft will be accepted. Milstein envisions using human monoclonals in this way to establish "a worldwide standardization of tissue typing for organ transplantation." Several research teams are investigating the possibility of using these antibodies to destroy the cells responsible for rejection. This would permit transplantation of organs that do not exactly match the "self" of the recipient.

Production of Pure Biochemical Reagents

Milstein points out that "a monoclonal antibody is a well-defined chemical reagent that can be reproduced at will," in contrast to conventional antiserum, which is a variable mixture of reagents that can never be reproduced once the original supply has been exhausted. Laboratories produce these antisera by injecting antigens into test animals, then identifying and isolating the antibody of choice. No two test animals yield the same composition of antibodies. Therefore, as monoclonals become more available, they are likely to supersede conventionally produced antibodies in many investigative and clinical laboratories.

Milstein cites standard blood tests as an example. Reagents for the tests—antibodies to the A and B red-cell antigens—are obtained from human serum by injecting donors with red cells of the appropriate group. This is potentially hazardous since a donor might have AIDS, hepatitis, or another viral disease. In addition, the donated serum must be carefully screened for unwanted antibodies whose activity could obscure the anti-A or anti-B reaction. This is why such reagents cannot be otained from animals; antibodies in the animal sera would recognize the red blood cells as foreign, eliminating the distinction between A and B groups.

Milstein's team has established that monoclonals used for these tests need not be human. He explains that "a reagent produced from mass cultures of hybrid myeloma cells that specifically recognizes group-A antigen has been tested in comparison with the best available commercial reagents and has been found to be equally effective."

Just as they can confine a reaction to a specific molecule, monoclonals can isolate a single component from a "dirty" mixture. This opens up a new approach to purification of natural products. Interferon, which is notoriously difficult to purify and obtain in quantity, has been purified by this technique. The same technology is employed to dissect a mixture of unknown substances into its components. Animals are immunized with the mixture; hybridoma clones are derived from fusing mouse myeloma cells and the lymphocytes of the animals. Antibodies from each clone remove different components from the mixture one by one. This method can be used to characterize normal and abnormal cells by their surface antigens, and to dissect structural members of biological materials such as the specialized parts of cells and pharmacologically active cell extracts.

Studies of Cell Development

Another exciting application involves the study of changes that cells undergo during human development. As fetal cells organize into tissues and organs, markers on the cells change and the changes can be tracked with antibodies. Researchers at Stanford have detected fetal cells in a mother's blood as early as 15 weeks after conception. The next step is to produce monoclonals against the fetal-cell markers in order to isolate the cells from maternal serum. Once isolated and grown in culture, biologists can examine their chromosomes for genetic defects. The final goal is to develop a simple, inexpensive test that can be done more safely and at an earlier stage in pregnancy than is now possible.

Tracking cells through differentiation becomes difficult because the cells are characterized, not by one, but by an ensemble of surface antigens. Thus, profiling them requires a large collection of monoclonals. This work is being facilitated by cytofluorometers and fluorescence-activated cell sorters, instruments that quickly measure the size and fluorescence of large numbers of cells to which monoclonals, tagged with fluorescent dye, have been attached. This enables a cell population to be sorted on the basis of surface-antigen pattern and size. Therefore, new surface molecules can be identified at the same time that different cell groups are distinguished from each other. Bruce Wainer of the University of Chicago uses this technique to learn how neurons in the brain change to cause disorders such as Alzheimer's disease.

Good results in the same area have been obtained with various blood-forming and lymphoid cells. A direct practical application is the diagnoses of various leukemias and related disorders. Researchers have employed mouse antibodies to detect leukemia in mice, as well as to recognize human cancer cells implanted in mice. Investigators at a number of laboratories are attempting to produce antibodies that recognize other cancer cells.

Monoclonals for various diagnostic purposes already are available from several pharmaceutical and biotechnology firms and commercially produced kits are used in many clinical research laboratories. *Business Week* has estimated that the U.S. market for these diagnostic kits will reach $485 million in 1985.

Potential Medical Applications

Cancer Therapy. The most dramatic application of monoclonals centers on cancer therapy. If these molecules seek out antigens on tumor cells, it is logical to pair them with drugs that destroy these cells. Such combinations are properly called immunotoxins, but someone coined the term "magic bullet" and it caught on. To make magic bullets, cancer cells with a tumor-associated antigen on their surfaces are injected into mice. The animals produce antibodies against the human antigen; then a drug is linked to the antibodies. When injected into a patient, the antibodies carry the toxin to the tumors where the bullet binds to the antigens and kills the cells.

Researchers are experimenting with diphtheria toxin, an enzyme that ruins a cell's ability to synthesize proteins. R. John Collier and D. Gary Gilliland of the University of California, Los Angeles, developed such a cancer-cell toxin. Hilary Koprowski and Zenon Steplewski of the Wistar Institute constructed a monoclonal that binds to colonrectal cancer cells. The two teams combined their efforts and have made immunotoxins that kill human colorectal cancer cells in laboratory cultures.

Michael I. Bernhard and his co-workers at the National Cancer Institute treated liver cancer in guinea pigs with monoclonals plus diphtheria toxin. This reduced but did not eradicate the tumors. Thus, this magic bullet failed to hit the bull's eye consistently enough to kill all malignant cells. Perhaps the "aim"—that is, the antibody—was not selective enough in binding to the target to be destroyed or separated from the antibody before it hit the tumor cells. Researchers are investigating these and other possibilities.

Other experimenters use a toxin called ricin, a protein found in castor beans. Stuart F. Schlossman of the Sidney Farber Cancer Institute in Boston linked ricin to monoclonals and injected them into patients with leukemia and lymph cancer. He has described his results as "impressive but very preliminary."

Attempts are underway to make magic bullets more effective by using genetic engineering to alter genes that encode instructions for making the toxins. The fragment of gene that researchers believe will improve the aim of the diphtheria-toxin bullet has been cloned by inserting it into bacteria. This genetically altered immunotoxin has not yet been used for human cancer therapy.

An alternate approach is to use antitumor antibodies. Dr. Ronald Levy of Stanford constructs such antibodies from mouse myelomas and human lymph cancer cells that have a unique antibody on their surface. The first person to receive this treatment was in the terminal stages of cancer with tumors that totaled over two pounds (a kilogram) in weight. After 5 weeks, the cancer regressed; after two years, the patient still appears free of cancer. However, people with such lymphomas sometimes experience spontaneous regression, and the patient underwent other types of therapy, including drugs and radiation, before receiving the monoclonals.

Levy has treated other lymphoma victims, some of whom responded and some of whom did not. In four of these patients, Stanford scientists found tumors with two types of cells, challenging the long-standing assumption that all cells in a tumor are identical. Monoclonals, which attack a specific type of cell, would not be effective against such tumors. "The implication for future therapy is that physicians will have to look for more than one type of cell in biopsies of cancerous tissue," notes Jeffrey Sklar of Stanford's School of Medicine. When more than one type is found, antibodies or drugs for each type will have to be administered.

Other researchers explore the possibilities of linking monoclonals with tumor-destroying radioactive isotopes or synthetic chemicals rather than natural toxins. Progress also is being made in applying monoclonals to diagnosis and treatment of viral diseases such as influenza and rabies. Even birth control has become an objective of this technology. Scientists at the Agricultural Research Council's Babraham Laboratory in England have prevented pregnancy in female mice treated with anti-progesterone monoclonals as long as 5 days after coitus.

Immunodeficiency Diseases. Another promising medical application involves treatment of bone marrow transplants for leukemia victims, who sometimes undergo whole-body irradiation or chemotherapy which destroys bone-marrow cells along with leukemic cells. Although these patients require a marrow transplant to replace cells necessary for blood production, the immune system may reject the transplanted marrow. To avoid this rejection, Daniel A. Vallera of the University of Minnesota and his co-workers treat marrow cells in culture with toxins linked to antibodies against cells responsible for rejection. The procedure works successfully in the laboratory and will be tested in patients.

The first few successes in treating immunodeficiency disorders with monoclonal-treated marrow grafts have generated interest in using these transplants to combat hereditary blood disorders, such as thalassemia and sickle-cell anemia. "Fewer than 50 percent of thalassemia patients have a compatible (matched antigen) donor," observes C. Dean Buchner of the University of Washington School of Medicine. "If marrow grafts (treated with monoclonals) become a standard therapy for this disorder, mismatched grafts would enable us to treat the remainder."

The exquisite specificity of monoclonals enables them to react with cells causing disease or rejection without harm to tissues and organs or other parts of the immune system. This makes them ideal for probing cell-surface antigens known to predispose people to a variety of autoimmune disorders in which the immune system attacks, rather than defends, its owner. These include types of arthritis, juvenile-onset diabetes, multiple sclerosis, psoriasis, chronic active hepatitis, ragweed fever, and several types of cancer. Isolating cell markers associated with these disorders will help scientists understand the connection between genes and antigens, as well as the role genes play in the susceptibility to autoimmune diseases. Developing monoclonals to neutralize the harmful products that these antigens stimulate the body to produce should enable medical researchers to find cures for these ailments.

Hugh McDevitt and his colleagues at Stanford University have successfully used this strategy to treat mouse models of multiple sclerosis, myasthenia gravis, and systemic lupus erythematosus (SLE). In one series of experiments, they immunized mice to produce pathological changes in the nervous system similar to those of multiple sclerosis. When the mice received monoclonals immediately before or after immunization, the expected brain and spinal cord changes did not occur. The scientists also ameliorated experimental myasthenia gravis without decreasing protection against a challenge by proteins from bacteria that cause tuberculosis. In other experiments, treatment with monoclonals induced remission of kidney damage caused by an SLE-like condition in mice. Ninety percent of the animals receiving treatment survived for 1 year, compared to 10 percent of the untreated controls.

When human monoclonals became available, McDevitt decided to switch his experiments to monkeys. However, he learned of the deaths of four of nine rhesus monkeys treated with low doses of these antibodies by other researchers. This surprised and disappointed the Stanford group, but they plan to proceed with the experiments. "I wouldn't have come this far if I did not think I could get to the point where I could treat someone," McDevitt declares.

The problem in monkeys may be peculiar to antibodies against antigens involved in autoimmunity, since monoclonals have been used successfully against other antigens. For further investigation, researchers need clones of human cells that make monoclonals against a variety of autoimmune antibodies. Carlo Croce has developed a variety of such clones, but they yield only small quantities of antibody. He is concentrating now on "constructing a system that will produce large quantities of any specific human antibody." Such monoclonals may someday be injected into animals to produce anti-autoantibodies, which in turn could be used to immunize humans.

Henry Kaplan's group developed two sets of human monoclonal antibodies against non-autoimmune diseases. One combats a toxin produced by a group of gram-negative bacteria that share a common cell-core structure. This toxin causes problems worldwide; it is responsible for 100,000 cases of shock and 35,000 deaths annually in the U.S. alone. To treat the infection, physicians use serum from affected volunteer donors.

The other human monoclonal may protect thousands of unborn infants against attack by their mothers' immune systems. Such attacks cause jaundice, developmental problems, mental retardation, and even death. Physicians presently control this incompatibility by giving a mother with Rh-negative factor in her blood a serum that neutralizes her system's attack on the blood of an Rh-positive baby. The first baby of a positive father and a negative mother usually is safe because the mother's immune system has not been sensitized to positive-type blood. When the baby is delivered, however, positive blood cells can leak into the mother's blood, leading to generation of anti-Rh antibodies that endanger subsequent positive babies. To prevent this, physicians inject her with serum containing anti-Rh antibodies shortly after delivery of the first child.

Engineered Monoclonal Antibodies

Because genes are the ultimate source of monoclonal antibodies, genetic engineering undoubtedly will play an increasing role in tailoring them for specific basic and medical applications. For example, John Collier and Donald Kaplan of the University of California, Los Angeles, note that eventually it may be possible to isolate the gene for a particular antibody, modify it to improve its affinity for a particular antigen, and link it to a gene producing an appropriate toxin. Bacteria or yeasts could then synthesize an immunotoxin as a single construct.

"Such combinations of biotechnologies, coupled with new types of instrumentation, promise spectacular advances in research and commerce," comments Leroy Hood. He combines monoclonal-antibody production, genetic engineering, and microchemical instrumentation in a single facility at the California Institute of Technology. "These biotechnologies will have a profound effect on the health sciences, as well as on many other areas including fundamental understanding of biology, agriculture, energy, and chemistry," he continues. If progress continues for the next 10 years as it has for the past 10 years, no one will be able to gauge the shape of the future. The possible applications appear virtually unlimited."

ADVANCED SCIENTIFIC COMPUTING

"A new paradigm has been born." "We now have theoretical, experimental, and computational science." "A new way of thinking in science." "It is now possible to compute things you can't measure." "The attitude toward computers for research marks a generation gap in the community of scientists."

Put so nakedly, these assertions smack of hyperbole. But if they are hyperbole, they are the exaggerations of expectations, not of unkept promises. For within about the past 5 years, computers have in fact created a new dimension of science. They have moved beyond their historic roles as laboratory work horses—to register and calculate data, to control processes—to become in many fields of science the gateway to new research frontiers.

Thus, by reading their printouts or scanning their monitors, scientists can now:

- Test ideas on the forces moving the earth's plates, by going forward or backwards millions of years;
- Track the path an electron takes within the magnetic field of a neutron star;
- Link a fragment of viral DNA to a human gene;
- Watch plasmas undulating within fusion reactors yet to be built;
- Form and reform digital clouds and watch tornados emerge;
- See galaxies born, watching their spiral arms take shape;
- Set the clock at the very (almost) beginning and recreate the universe;
- Begin to think about confirming or denying the root theories of proton and neutron structure, to test our ideas on the nature of matter; and
- Predict how a spacecraft will glide through the atmosphere of Jupiter.

Three *prima facie* conditions have made these statements possible. One is that mathematical models—a set of equations articulating a physical law, such as the behavior of flowing fluids, that is in principle convertible to algorithms, or instructions, needed to direct a computer—were available. Second, while these equations were often too complex for exact solution, enough was understood of the underlying science so that believable simplifications could be imposed. And third, the computational power (the hardware) became available to solve approximate forms of these equations, which were typically differential equations; that is, descriptions of the relations between quantities (for example, a mixture of chemical reactants and products) and their rate of change with, time, temperature, or concentration.

Nature tends to be continuous, meaning that physical parameters vary smoothly over an unbroken domain. For the computer attempting to simulate, for instance, a storm cloud, continuity means calculating quantities like pressure and temperature for an infinite number of spatial points. That cannot be done. What can be done is to create a network of spaced points, with the number and density of points—the spacing between them—depending on the topic at issue, the available computing power, and the needed precision.

Each point becomes a calculational locus for the computer, a point where it calculates a given algorithm expressing some fundamental physical law, using quantities attached to that point. The quantities may link the density, velocity, and temperature of a flowing gas; the mechanical stresses on a solid; or the various components of electromagnetic or nuclear forces. The important concept is that each point, each computational locus, is a unit of a much larger "universe", one that typically changes in time.

The finer the mesh, the more believable the result, the simulation. A simple calculation (simulating turbulent air flow over an aircraft wing, for example) requires a three-dimensional grid of about one million nodes. Each of those nodes may have anywhere from 5 to 30 numerical quantities attached to it, with the quantities related to one another and to sets of quantities on adjoining nodes. A new value for each of 1 million nodes may demand 10 to 500 arithmetic operations, for a total of 10^{13} computations. Every quantity must be storable in memory, and must be located, revised, and restored as the computation iterates. This adds up to an enormous appetite for both computational speeds and capacious, rapidly accessible memories.

Confluence

It is simplistic to attribute the current explosion of computational science to the debut of the current generation of supercomputers. The gap between desires and needs before the advent of contemporary supercomputers did not stop the use of the computer to do "experiments"; it simply limited what could be done. However, while simpler "experiments" were run on the minicomputers available to academic science in the 1970's, these were typically too coarse in their approximations, too slow for real-time experiments, and invariably too expensive.

Massive computing also has a long history both in engineering research and in some scientific fields, such as geophysical and astrophysical fluid dynamics. And supercomputers are not really new. For, by definition, a supercomputer is the fastest machine at any given time capable of computing scientific problems.

What then, is new? The real answer is a confluence of converging trends. Theory has been an important forcing function, especially quantum theories, applicable in physics, chemistry, and fluid mechanics. Another is that the "graininess," the complexity, of the problems which scientists attempt has intensified. Another engine driving computational science is the expanding community of scientists versed in large-scale computation and able to apply it imaginatively to their own research interests, with that desire catalyzed by declining computational costs. The sorts of problems presented to scientists have changed.

Fortuitously, while computable problems were becoming grainier, more complex, so were integrated circuit chips. About a dozen or so transistors could be put on a chip in the early 1960's; now hundreds of thousands can be. Those advances in underlying componentry made it possible to build very fast computers with large memories at tolerable costs per computation. For example, simulating air flowing over a wing today takes about half an hour and cost about $1,000 in supercomputer time. Twenty years ago, that same simulation would have cost about $10 million and would have taken about 5 years to complete.

The remarkable present day computational capacities are due largely to the current generation of commercial supercomputers: the Cray 1, made by Cray Research, Inc., and the Cyber 205, built by the Control Data Corporation. An antecedent of sorts was the Iliac IV, designed at the University of Illinois and installed in 1972 at the Ames Research Center of the National Aeronautics and Space Administration, where it dealt with some of the most complex aerodynamics problems ever written. While Iliac IV was dismantled in the early 1980's, the Cray I, and subsequently the Cyber 205, outgrew their governmental purposes, and began to be used for scientific problems.

Vectors

What makes these machines so powerful? First, they are vector computers; that is, they can perform identical arithmetic operations—addition and the like—on an array of numbers. This saves time and memory capacity, and distinguishes them from one-at-a-time arithmetic, or scalar processing. Secondly, they embody pipelining, a form of parallelism or concurrent processing; the classical and apt analogy of pipelining is the assembly-line manufacture of a car, albeit rather than a car it is the parts of an algorithm that are worked on concurrently, with a consequent gain in computing efficiency.

Available supercomputers differ in important respects, especially in the sizes of the vector arrays they handle, their arrangements for storing data, the stages of a computation at which they go to main memory or to registers, the way they handle instruction sets, and the like. They are cousins in their computing capacities. Where the personal computer deals with about a million instructions each second, these supercomputers have peak computing speeds exceeding 100 million operations per second.

They also share (what are in the world of academic science) high costs, these being several million dollars for each machine. Simply an hour on one supercomputer can cost considerably more than $1,000. Thus, it isn't surprising that a number of cheaper alternatives with quite respectable power for computing scientific problems have been built, largely in the universities. These machines are built to do particular tasks very well, typically, tasks in which the numbers change but the way they are calculated does not. However, the price of such dedication is a loss of flexibility.

The Limit of 1,000. This, then, is the bestiary of advanced scientific computing. There are the "standard" supercomputers, the Cray I and the Cyber 205, now becoming accessible to university science; there are their successors, such as the Cray XMP (two or more linked Cray I's), and there are a scattering of special-purpose machines, often elegant and effective in their design and construction. As astounding as these machines are, they provoke a certain level of dissatisfaction in researchers who have used them and learned what may be possible. The common refrain is that machines some 1,000 times faster than those that exist are needed.

Why? Remembering that supercomputers are adept at massive calculations of data feeding into algorithms, the upshot is that the more data points calculated, the less squishy the approximation and the more revealing the result. The aim is to calculate ever finer "meshes" of data. That generality has to be fitted to the field at issue, but it is applicable whether the problem is stellar evolution, modeling materials not even made, testing the architecture for an unbuilt computer, or simulating the internal events of an aging star within a computer.

The uses are growing almost exponentially, and therefore any examples are dated. However, virtually every example offers some general lessons of the power of computers embodying very high speeds and capacious memories. Some examples of this follow.

Astrophysics

Supersonic Jets. Earlier this decade, radio telescopes detected an enormous number of jets of gas streaming out of the centers of galaxies and quasars. These radio jets are the largest coherent structures in the universe, being anywhere from thousands to millions of light years long. The immediate questions are obvious: What is their source? How do these jets maintain their structure for such enormous distances, rather than breaking up, as a wave would upon a shore? What gives them their structure?

The proposal was that these were jets of gas boring into the intergalactic void at supersonic speeds. That hypothesis reduced an astounding phenomena to human scale, for some 100 years ago the physicists, Ernst Mach (who gave his name to units of the speed of sound) and Peter Salcher, studied supersonic air flow in their laboratory. Further, the basic equations for modeling supersonic flow were known. The difference between what Mach and Salcher did and the jets blowing out of the galaxies lay not in the laws of physics, but only in scale; rather than centimeters it was light years.

With the seminal assumption that the jets were supersonic gases, their flow could be simulated on a computer, using basic equations of hydrodynamics; a mesh of grid points, calculational locii, was laid down, and conditions of density, temperature, entropy, etc. attached to these points. The product is the jets propagating across a computer screen. They hold their structure, as the real jets do; within them are the same structures—the "knots" where pressure waves meet—that Mach saw in his laboratory experiments.

Stellar Evolution. Computers and stellar evolution—how stars are born and die—grew up together. An appreciable fraction of the time of the MANIAC, an early computer built by John von Neumann and his colleagues, was spent on studying stellar evolution. Most stars are hydrogen burners, gaining their enormous energy by fusing hydrogen into helium. But in time these "main sequence" stars exhaust their hydrogen and begin to burn helium and even heavier elements. What was originally a simple furnace becomes a very complicated one, with a patchwork of reaction zones within the star, its internal structure very sensitive to temperature changes. Convection currents move mass from one reaction zone to another, changing burning rates. Rather than remaining a smoothly-varying structure, a star becomes a kaleidoscope of virtually independent furnaces. What those furnaces are doing, how they affect one another, how they change with time and other forces becomes a virtually insuperable problem. While with the jets the underlying algorithms are clear, they are not so for these stars. What is the role, for example, of magnetic fields in heat transfer? In an attempt to answer these questions, and even to move beyond them, work now underway involves creating new algorithms to be run on the fastest computers available and, optimally, on the much faster computers of the future.

Airplanes, The Atmosphere, and Storms

Weather and bumpy airplane rides are the most obvious examples of turbulent fluids. Less obviously, turbulent gases and liquids—the flows over an airplane wing or a car, the wind patterns over a continent, the internal anatomy of a tornado—are a research frontier in computational science. Turbulence is a continuously disordered flow; while the tornado, or cloud, or wind moves in a seemingly coherent way, their interior speed and direction at any point are changing constantly and erratically. The onset of turbulence, when a smoothly flowing fluid becomes undone, remains only roughly predictable and only in specific situations.

The basic equations of moving fluids, of fluid dynamics, the Navier-Stokes equations, are relatively ancient; the difficulty is that the cascade of everchanging velocities within a fluid (turbulence) makes an exact solution of these equations virtually impossible for any situation that is interesting. The game then becomes using computers to integrate (in effect) the net result of many small-scale flows into a larger picture of what the fluid does as it flows over a wing, a mountain range, a car, or a house.

Clouds and Tornados. What are the birthplaces of tornados? How do they form? How can they be predicted? Those seemingly unyielding questions are again candidates for the Navier-Stokes equations, the fundamental statements of what a flowing fluid is doing quantitatively at any given point. Using these equations, translated into algorithms penetrable to a supercomputer, and judiciously applying initial conditions (wind, density, temperature calculated for a grid of points one kilometer apart) one can watch a cloud on a protean course: growing from a small cloud to the tell-tale internal structures of a tornadic cloud, one from which a tornado can emerge.

Plasma Physics

Hydrogen plasmas, fluids of ionized particles, are the most common matter of the universe, the stuff of stars. Less exotically, they are likely to form the "fuel" of fusion reactors, in which the intent is to obtain energy by extracting the energy released when hydrogen nuclei merge to form helium. The questions are formidable and many: What happens to particular particles as they move through the plasma, and as they hit reactor walls? How do neutrons streaming out of a plasma affect the surrounding magnets? What recipe for plasma energies, densities, confinement times, and geometry works best? How does one estimate the effects of energy-bearing neutrons streaming out of the fusion reactor, without building a reactor to study the effects directly?

These are apt questions for computational science. A fusion plasma will have on the order of 10^{15} particles per cubic centimeter, with each particle carrying a charge and affecting both near and far particles. In a computer run, the electrical and magnetic fields created by the collective motions of these particles is calculated, the effects of the fields on the particles approximated, and then, recursively, the follow-on effects on the fields determined. The result is a simulation of a fusion plasma within conditions specified by the experimenter, with those conditions tunable so that the changes in parameters such as particle density, the configuration of containing fields, and the temperature, can be smoothly varied and the consequence for a sustainable fusion reaction assayed.

Computer Design

In a sort of hermaphroditic tactic, supercomputers can be used to create their descendents. A computer's essentials are the integrated circuit chips, on which data and instructions are stored (memory chips) and the instructions executed (microprocessors). The *sine qua non* of computers of the future, of the sort discussed below, are new chip designs. These would possibly incorporate new materials—for example, gallium arsenide rather than silicon. They will certainly be bristling with more of the components, such as transistors, by which the chips control the flow of on-off electrical impulses that are the end result of the most complex equations.

Building these chips is both difficult and expensive, but less so if done first within a high speed computer. Thus, one can, and does, simulate a new semiconductor structure within a computer, and then "send" an electron crashing through it, just as it would in a working chip. The picaresque history of the electron is taken, and, as the semiconductor structure is retuned on the computer, the varying histories that result are compared to see how particular changes affect what the electron does.

A level above electron tracking is that of designing three-dimensional chips. The problem is optimal interconnection of those layers, matching semiconductor structures so as to enhance switching speeds rather than to dampen them by injudicious arrangements.

Chemical Engineering

An engineer faced with designing a new chemical plant or refinery embodying new processes faces some daunting challenges. Since the plant is basically a vessel for a cascade of connected chemical reactions, all its various parts—heat exchangers, the reactors themselves, separation units, etc.—are highly interconnected. If one goes awry, the entire process is threatened. Processes within the plant are invariably complex and often poorly understood. Neither the interactive effects of different reactants nor the downstream effects of loss or excess of a particular reactant are always known.

One's goal is to optimize while conditions at different parts of process are changing with time. Programs such as FLOWTRAN are used to simulate steady-state processes within different parts of a plant; but none as yet simulate random, unexpected, yet interconnected changes for an entire plant. The difficulty in such simulation is not simply having sufficient computing power, but also in creating algorithms for an immensely dynamic and complicated process.

A related issue is simulating not only a future plant, but also operating a real one—the freight-train phrase is "on-line whole plant process optimization." While computers are being used to control existing processes, they are not being used—because neither the software nor hardware is there yet—to optimize the entire process; that is, to detect a disturbance in one part of the plant, and then correct it throughout so that the process continues to run optimally.

John Von Neumann and Complexity

These samplings of an exploding enterprise, to be catalyzed by the increasing accessibility of supercomputers to university scientists, yield some generalities applicable to computational science. One is that the computer is increasingly a tool of discovery, not simply a way to refine observations. Thus, computer simulations showed the internal anatomy of the radio jets, or the direct dependency of the immediate history of a storm cloud on its immediate environment.

Further, in one sense complexity no longer matters; supplied with the algorithm, the supercomputer doesn't care; and, however complex the problem, a grid of points with numbers attached can be thrown over it, and (allowing for reasonable simplifications) calculated. It also becomes a simple matter to unravel complexities by systematically testing assumptions. For example, radio jets are shrouded by a cocoon of gas. The computational simulation of jets showed that the existence of these cocoons depends directly on the density of jets and of the medium they stab into. That discovery was made by changing the input statement for density in the program running the computer; observations weren't needed.

It is this insouciance before complexity that is driving computational science, given reality by the arrival of computers of sufficient speed and memory to enable experiments to be done in reasonable time. As Kenneth Wilson of Cornell University, 1983 Nobelist in physics, observes: "If you compare the situation today with that in the 1960's, what has changed is the complexity of the problems which people are willing to tackle; indeed, there's now a qualitative difference in the kinds of problems people study from the first 300 years of science."

The liberating attitude of supercomputers toward complexity pops up in many ways: for example, in aerodynamics, calculations in two dimensions are becoming routine, and those in three-dimensions are becoming tractable. Rather than looking at two or three bodies interacting, the computer now looks at many, if not an infinite number, whether the particles of a fusion plasma, the florentine complexities of a chemical plant, the countless events as an electron moves through a transistor crystal, the roiling and jumbled interiors of aging stars, or the boggling interactions involved in calculating the forces between quarks.

A NSF report on computational physics in 1981 pointed out that "complexity arises not from 'bad taste' in the choice of problems, but inevitably as theory advances." The same point was made, more presciently, in 1946 by John von Neumann, who, with Alan Turing, created the concepts underlying today's digital computers. Because the statement is a rare example of a prediction actually confirmed by events some 40 years later, it's worth quoting at length. Von Neumann asked his audience:

> To what extent can human reasoning in the sciences be more efficiently replaced by mechanisms? What phases of pure and applied mathematics can be furthered by the use of large-scale, automating computing instruments? Our present analytical methods seem unsuitable for the solution of the important problems arising in connection with nonlinear partial differential equations....This phenomenon is not of a transient nature, but we are up against an important conceptual difficulty. . . .

What von Neumann was in effect saying was that with large enough computers, problems that were intractable to solution (those describing non-linear events, from the weather to plasmas to interiors of stars, where variables change randomly) could be solved numerically: imposing conditions, specifying quantities, and then letting computers have a go.

The Future

The third commonality of the examples above is that they all segue into very specific reasons why faster computers would broaden and deepen the science to be done. In the case of stellar evolution, the equations used to simulate radio jets must be enhanced by including the effects of magnetic, electrical, and plasma effects, an imposition of computational baggage too heavy for contemporary machines. In fluid dynamics, the problem is to model airflow in three dimensions over an entire airplane, for example. Further, poor resolution owing to inadequate computing power has left a trail of expensive airplane design problems; for example, simulations incorrectly predicted wing flow over the C-141 and airframe drag for the F-111, F-102, and F-106, leading to either costly modifications or reduced performance. Modeling storms remains largely a two-dimensional act, constraining the simulation of full tornadic storms and tornados themselves. Similar constraints apply to the powerful and unpredictable downdrafts from clouds—wind shears—that have struck down airplanes. To design three-dimensional chips efficiently for the next generation of computers, movies have to be made of various designs to see their real-time switching characteristics; that is, the in-and-out movements of electrons. That again requires a substantial increase in computing power, both in switching speeds and memory.

More computing power not only tightens the mesh of points, to reduce time scales and expand space dimensions from one or two to three, but also enables the scientist to experiment with the computer: to tune through different densities of the stratosphere, to thicken the particle mass in a fusion plasma, to blow matter past the accretion disks surrounding black holes and observe the consequences, or to do a chemical reaction using temperatures and pressures beyond the reach of any laboratory. Whatever the particulars, the root questions are the same: Is the result reasonable? Do they enhance the assumptions in the computation? Is the physics or the chemistry right?

It is by now a chronic condition in computational science that the algorithms have been written, but are not computable so as to produce believable results. "What happens," Kenneth Wilson says, "is that the range of lengths or time scales or whatever that is put into the simulation totally outruns any computer."

Another force in the quest for speed is graphic displays of the results of an experiment while it is being run, while the experimenter has time to change his assumptions. Indeed, says Wilson, "people are beginning to use computer graphics to feed intuition back to the human mind; that is, watch the simulation as it's happening in the computer. What does not work is to show a frame, then 30 seconds later show another frame. One can't interact very effectively if each interaction requires 7 days. And if there's something you want to change, there's another 7 days."

How to Go Faster. These needs coalesce into a cry for faster computers. Maximum computation rates are now about 1,000 million instructions per second, or mips. The desire is for rates of 20,000 mips, and even, in about 10 years, 100,000 mips. Those speeds are unattainable with the present computer architecture: instructions executed serially. They are, in principle, attainable by parallel or concurrent architectures: computers executing hundreds, thousands, or hundreds of thousands of instructions simultaneously. The algorithms, the computer languages, the operating systems that can coordinate these large numbers of calculations are also required.

In short, attaining a thousand fold increase (which would, for example, enable real time graphics of three-dimensional experiments) is a forcing function for both hardware and software. For hardware, the response is in the astonishing reduction of circuit sizes in chips, increasing switching speeds, so that instructions are executed faster; and it is in providing ever larger memory capacities. Making these chips depends on new frontier technologies for imprinting circuits on semiconductor beds, including X-ray, ion, and electron beam lithographies.

Such very large scale integrated, (VLSI) circuit chips will be the "bricks" of parallel architectures, architectures created of hundreds, if not thousands, of interconnected microprocessors, each processor capable of handling one or more instructions. Over 70 designs for parallel computers embodying such ideas have been proposed, almost exclusively within the universities, and it will cost on the order of $20 million to actually build one.

There are, in fact, a number of parallel machines now operating in Britain and the United States, though most are experimental. Parallel machines will require different algorithms than current computers; while current algorithms may be adaptable, especially by creating automatic compilers to translate algorithms into machine language interpretable by the architecture of the computer, it's problematic whether such "reheated" programs will squeeze the maximum work out of these new machines. The difficulty is writing programs for unbuilt machines. Experimentation is impossible, and the very act of having programs orchestrating perhaps thousands of simultaneous events, makes it enormously more difficult to trace "bugs" or errors in the program. Further, operating systems must be written to handle communications among thousands of cooperating processors.

Overall, the move into parallel territory demands new conceptual strategies in formulating a problem, new algorithms to shape the problem for the computer, new programming methods to interpret the problem in computer terms, and new compilers to translate high-level languages understandable to a user into machine language. More sophisticated graphics to interpret the complexities of parallel computation will also be needed.

These are, however, the demands of frontiers, not obstacles. For the creation of new algorithms being triggered by the prospective arrival of massively-parallel supercomputers will seed new strategies for solving problems, with these in turn driving the creation of much better algorithms.

Further, the achievements discussed here came from computers made available to a few universities only in the early 1980's. Yet in 5 years a "new paradigm" was born. Complexity is now the norm; new science has been discovered; the supercomputer has become a working tool for a small but surely a critical mass of students. As the price of present supercomputer declines, perhaps quite sharply, it will become to the universities what the minicomputers were in the 1970's. And as faster machines emerge containing still unknown architectures, they will create the bowwaves into understanding nature at her most abstruse. An expanding generation of students and their teachers will sit before their monitors, and watch as in tell-tale colors their monitors show them the innards of stars never seen; the creation of the universe; a thought slipping through a brain; storms taking shape and loosing their tornadoes, their thunder, and lightning; and new airplanes that fly first in the computer and then out into the real world.

Appendix I
Statistical Tables

Appendix Tables

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CHAPTER 1. THE INTERNATIONAL SCIENCE AND TECHNOLOGY SYSTEM

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Appendix table 1-1. Scientists and engineers[1] engaged in R&D and total labor force population, by country: 1965-83

Country	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Scientists and engineers[1] per 10,000 labor force population																			
France	21.0	23.3	25.3	26.4	27.1	27.3	27.9	28.2	28.5	28.9	29.4	29.9	30.0	31.0	31.6	32.4	36.3	37.9	39.1
West Germany	22.7	22.4	24.9	26.2	28.4	30.8	33.4	35.6	37.1	37.8	38.6	39.2	41.8	NA	45.3	NA	46.8	47.8	NA
Japan	24.6	26.4	27.8	31.2	30.8	33.4	37.5	38.1	42.5	44.9	47.9	48.4	49.9	49.4	50.4	53.6	55.6	57.1	58.1
United Kingdom	19.6	NA	NA	20.8	NA	NA	NA	30.4	NA	NA	31.2	NA	NA	33.2	NA	NA	35.8	NA	NA
United States	64.7	66.9	67.2	68.0	66.9	64.4	61.0	58.3	56.8	56.1	55.8	55.8	56.4	57.2	58.4	60.7	62.7	64.6	66.2
U.S.S.R. (lowest)	44.8	47.1	50.7	53.5	56.5	58.1	63.0	67.2	71.3	74.6	78.1	79.6	80.9	82.8	84.4	86.4	88.8	91.7	92.9
U.S.S.R. (highest)	48.2	51.4	55.3	58.8	62.1	64.0	69.3	74.4	79.4	83.1	87.2	89.1	90.8	93.2	95.5	97.9	100.8	104.4	106.5
Scientists and engineers (in thousands)																			
France	42.8	47.9	52.4	54.7	57.2	58.5	60.1	61.2	62.7	64.1	65.3	67.0	68.0	70.9	72.9	74.9	85.5	90.1	92.7
West Germany	61.0	60.0	64.5	68.0	74.9	82.5	90.2	96.0	101.0	102.5	103.7	104.5	111.0	NA	122.0	NA	128.2	131.4	NA
Japan	117.6	128.9	138.7	157.6	157.1	172.0	194.3	198.1	226.6	238.2	255.2	260.2	272.0	273.1	281.9	302.6	317.5	329.7	342.2
United Kingdom	49.9	NA	NA	52.8	NA	NA	NA	76.7	NA	NA	80.5	NA	NA	87.7	NA	NA	95.7	NA	NA
United States	494.5	521.1	534.4	550.4	555.2	546.5	526.4	518.3	518.3	525.1	532.7	546.3	568.2	594.2	622.0	658.7	691.4	723.0	750.0
U.S.S.R. (lowest)	521.8	556.5	607.8	650.8	698.8	730.1	804.2	872.3	938.9	997.0	1,060.7	1,098.0	1,134.2	1,178.2	1,217.8	1,262.4	1,311.8	1,368.6	1,399.0
U.S.S.R. (highest)	561.4	607.6	662.6	715.2	767.5	803.6	884.2	964.5	1,045.1	1,110.6	1,184.3	1,229.1	1,272.8	1,326.0	1,376.5	1,430.4	1,489.4	1,558.0	1,603.0
Total labor force (in thousands)																			
France	20,381	20,522	20,676	20,744	21,117	21,430	21,575	21,717	21,970	22,154	22,205	22,441	22,697	22,895	23,050	23,147	23,532	23,753	23,690
West Germany	26,887	26,801	25,950	25,968	26,355	26,817	27,002	26,990	27,195	27,147	26,884	26,651	26,577	26,692	26,915	27,191	27,373	27,465	27,486
Japan	47,870	48,910	49,830	50,610	50,980	51,530	51,860	52,000	53,260	53,100	53,230	53,780	54,520	55,320	55,960	56,500	57,070	57,740	58,898
United Kingdom	25,498	25,632	25,490	25,378	25,376	25,308	25,207	25,267	25,614	25,658	25,878	26,093	26,209	26,342	26,559	26,701	26,718	26,757	26,776
United States	76,401	77,892	79,565	80,990	82,972	84,889	86,355	88,847	91,203	93,670	95,453	97,826	100,665	103,882	106,559	108,544	110,315	111,872	113,226
U.S.S.R.	116,494	118,138	119,893	121,716	123,584	125,612	127,672	129,722	131,610	133,600	135,767	137,987	140,140	142,214	144,201	146,068	147,753	149,215	150,521

[1] Includes all scientists and engineers engaged in R&D on a full-time-equivalent basis (except for Japan, whose data include persons primarily employed in R&D excluding social scientists, and the United Kingdom, whose data include only the Government and industry sectors.

Note: NA = Not available.

Note: Estimates are shown for most countries for later years and for the United States in 1966 and 1967. A range has been provided for the U.S.S.R. because of the difficulties inherent in comparing Soviet scientific personnel data. The figures for West Germany increased in 1979 in part because of increased coverage of small and medium enterprises not surveyed in 1977.

See figure 1-2.

SOURCE: Council of Economic Advisors, *Economic Report of the President*, 1984, p. 254; OECD, *Science and Technology Indicators, Recent Results*, June 1984, and unpublished statistics; National Science Foundation, *National Patterns of Science and Technology Resources, 1984* (NSF 84-311); Dr. Robert W. Campbell, *Reference Source on USSR R&D Statistics, 1950-1978*, National Science Foundation, 1978; Steven Rapawy, *Estimates and Projections of the Labor Force and Civilian Employment in the U.S.S.R., 1950 to 1990*, Foreign Economic Report No. 10, U.S. Department of Commerce, 1976, p. 19; and Robert W. Campbell, *Soviet R&D Statistics, 1970-1983*, National Science Foundation, 1984.

Appendix table 1-2. National expenditures for performance of R&D as a percent of gross national product (GNP), by country: 1961-85

Year	France[1]	West Germany	Japan	United Kingdom	United States	U.S.S.R.
	R&D expenditures to GNP[2]					
1961	1.37	NA	1.39	2.47	2.73	NA
1962	1.47	1.25	1.47	NA	2.73	2.64
1963	1.55	1.41	1.44	NA	2.87	2.80
1964	1.82	1.57	1.48	2.30	2.96	2.87
1965	2.00	1.72	1.52	NA	2.89	2.85
1966	2.07	1.81	1.46	2.32	2.88	2.88
1967	2.12	1.96	1.52	2.30	2.89	2.91
1968	2.08	1.98	1.60	2.26	2.82	NA
1969	1.93	1.82	1.64	2.27	2.71	3.03
1970	1.92	2.06	1.85	NA	2.63	3.28
1971	1.90	2.18	1.85	NA	2.48	3.46
1972	1.90	2.20	1.86	2.11	2.40	3.71
1973	1.77	2.09	1.90	NA	2.31	3.81
1974	1.79	2.13	1.97	NA	2.29	3.74
1975	1.80	2.22	1.96	2.19	2.27	3.78
1976	1.78	2.15	1.95	NA	2.27	3.61
1977	1.76	2.14	1.93	NA	2.23	3.54
1978	1.76	2.24	2.00	2.24	2.22	3.54
1979	1.81	2.40	2.09	NA	2.27	3.59
1980	1.84	2.42	2.22	NA	2.38	3.76
1981	2.01	2.49	2.38	2.41	2.43	3.75
1982 (Prel.)	2.10	2.58	2.47	NA	2.58	3.68
1983 (Est.)	2.15	2.57	2.61	2.24	2.62	NA
1984 (Est.)	2.22	NA	NA	NA	2.62	NA
1985 (Est.)	2.27	NA	NA	NA	2.70	NA
	R&D expenditures (national currency in billions)[2]					
1961	4.5	NA	275.5	0.68	14.3	NA
1962	5.4	4.5	319.3	NA	15.4	5.2
1963	6.4	5.4	368.3	NA	17.1	5.8
1964	8.3	6.6	438.1	0.77	18.9	6.4
1965	9.8	7.9	508.6	NA	20.0	6.9
1966	11.0	8.8	576.6	0.89	21.8	7.5
1967	12.2	9.7	702.5	0.93	23.1	8.2
1968	13.1	10.6	877.5	0.99	24.6	9.0
1969	14.2	10.9	1,064.7	1.07	25.6	10.0
1970	15.0	13.9	1,355.5	NA	26.1	11.7
1971	16.6	16.5	1,532.4	NA	26.7	13.0
1972	18.3	18.2	1,791.9	1.35	28.5	14.4
1973	19.8	19.2	2,215.8	NA	30.7	15.7
1974	23.0	21.0	2,716.0	NA	32.9	16.5
1975	26.2	23.0	2,974.6	2.30	35.2	17.4
1976	29.8	24.2	3,320.3	NA	39.0	17.7
1977	33.2	25.7	3,651.3	NA	42.8	18.3
1978	37.7	28.9	4,045.9	3.68	48.1	19.3
1979	44.1	33.5	4,583.6	NA	54.9	20.2
1980	51.0	35.9	5,246.2	NA	62.6	22.3
1981	62.5	38.4	5,982.4	6.14	71.8	23.4
1982 (Prel.)	74.8	41.3	6,528.7	NA	79.3	24.6
1983 (Est.)	84.7	43.0	7,180.8	6.79	86.6	25.7
1984 (Est.)	95.0	NA	NA	NA	95.9	26.6
1985 (Est.)	104.0	NA	NA	NA	106.6	NA

(Continued)

Table 1-2 (continued)

Year	France[1]	West Germany	Japan	United Kingdom	United States	U.S.S.R.
	Gross national product (national currency in billions)					
1961	328.4	331.4	19,852.8	27.5	524.6	NA
1962	367.2	360.5	21,659.5	28.9	565.0	197.2
1963	412.0	382.1	25,592.1	30.8	596.7	206.8
1964	456.7	419.6	29,661.9	33.5	637.7	223.2
1965	489.8	458.2	33,550.2	36.0	691.1	242.1
1966	532.0	487.4	39,452.0	38.4	756.0	260.1
1967	574.8	493.7	46,175.6	40.5	799.6	282.0
1968	630.0	535.2	54,689.2	43.8	873.4	NA
1969	734.0	597.7	64,850.8	47.1	944.0	329.6
1970	782.0	676.0	73,128.0	51.6	992.7	356.2
1971	873.1	756.0	82,725.8	57.8	1,077.6	375.7
1972	961.3	827.2	96,424.0	63.9	1,185.9	388.6
1973	1,121.3	920.1	116,636.3	74.2	1,326.4	412.2
1974	1,284.4	986.9	138,044.6	84.3	1,434.2	441.0
1975	1,452.0	1,034.9	151,797.0	105.2	1,549.2	460.5
1976	1,677.8	1,125.0	170,290.0	125.7	1,718.0	490.0
1977	1,885.0	1,200.0	188,804.3	143.2	1,918.3	516.6
1978	2,141.0	1,290.7	202,708.0	164.6	2,163.9	545.1
1979	2,442.0	1,395.3	218,894.0	191.1	2,417.8	563.2
1980	2,765.0	1,484.2	235,834.0	229.8	2,631.7	593.1
1981	3,110.6	1,543.1	251,259.0	254.8	2,957.8	624.2
1982 (prel.)	3,566.9	1,599.0	263,984.0	278.1	3,069.3	667.8
1983 (est.)	3,935.0	1,671.0	274,639.0	303.2	3,304.8	NA
1984 (est.)	4,277.2	NA	NA	NA	3,661.3	NA
1985 (est.)	4,579.6	NA	NA	NA	3,948.2	NA

[1] Gross domestic product.

[2] Gross expenditures for performance of R&D including associated capital expenditures except for the United States where total capital expenditure data are not available. U.S. estimates for the period 1972-80 show that the inclusion of capital expenditures would have an impact of less than one tenth of one percent of the R&D/GNP ratio.

Note: NA = Not available.

Note: The figures for West Germany increased in 1979 in part because of increased coverage of small and medium enterprises not surveyed in 1977.

SOURCE: International Monetary Fund, *International Financial Statistics*, 30 (May 1977); vol.31 (May 1978); vol.31 (August 1978); vol. 32 (January 1979); and vol.33 (August 1980); U.S. Department of Commerce, *International Economic Indicators* (June 1984); OECD, *Science and Technology Indicators Recent Results*, June, 1984 and unpublished statistics; National Science Foundation, *National Patterns of Science and Technology Resources 1984* (NSF-84-311); Robert W. Campbell, *Reference Source of Soviet R&D Statistics*, 1950-1978, National Science Foundation, 1978, Robert W. Campbell, *Soviet R&D Statistics, 1975-1980*, National Science Foundation, 1983, and Robert W. Campbell, *Soviet R&D Statistics, 1970-1983*, National Science Foundation, 1984.

See figure 1-3.

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Appendix table 1-3. Scientific workers in the Soviet Union, by sector: 1970-1982

Year	VUZy higher education	Industry	Science sector						Total low estimate	Total high estimate
			Low estimate			High estimate				
			Total	Academy system[1]	Branch and department system	Total	Academy system[1]	Branch and department system		
	Thousands									
1970	65.3	47.6	617.2	105.5	511.7	690.7	118.1	572.6	730.1	803.6
1971	71.4	52.0	680.8	111.0	569.8	760.8	124.0	636.8	804.2	884.2
1972	75.5	58.4	738.4	119.6	618.8	830.6	134.6	696.0	872.3	964.5
1973	79.7	62.6	796.6	125.9	670.7	902.8	142.6	760.2	938.9	1,045.1
1974	84.6	63.4	849.1	129.9	719.2	962.6	147.3	815.3	997.0	1,110.6
1975	89.0	64.3	907.4	137.9	769.5	1,031.0	156.7	874.3	1,060.7	1,184.3
1976	92.4	65.1	940.5	143.0	797.5	1,071.6	162.9	908.7	1,098.0	1,229.1
1977	95.3	66.0	972.9	149.8	823.1	1,111.6	171.2	940.4	1,134.2	1,272.8
1978	98.9	66.8	1,012.5	155.9	856.6	1,160.3	178.7	981.6	1,178.2	1,326.0
1979	102.6	67.8	1,047.4	168.6	878.8	1,206.1	194.2	1,011.9	1,217.8	1,376.5
1980	104.7	68.6	1,089.1	177.5	911.6	1,257.1	204.9	1,052.2	1,262.4	1,430.4
1981	107.8	69.6	1,134.4	182.6	951.8	1,312.1	211.2	1,100.9	1,311.8	1,489.4
1982	109.7	70.4	1,188.5	186.6	1,001.9	1,377.9	216.3	1,161.6	1,368.6	1.558.0

[1] Breakdown estimated by National Science Foundation based on the distribution of "Scientific Workers" in the science sector overall.

SOURCE: Robert W. Campbell, *Soviet R&D Statistics, 1970-1983*, National Science Foundation, 1984

Appendix table 1-4. Estimated non-defense R&D expenditures as a percent of gross national product (GNP), by country: 1971-85

Year	France[1]	West Germany	Japan	United Kingdom	United States
	Estimated non-defense R&D expenditures as a percent of GNP				
1971	1.46	2.03	1.84	NA	1.68
1972	1.50	2.08	1.84	1.50	1.63
1973	1.38	1.94	1.89	NA	1.62
1974	1.43	1.98	1.96	NA	1.69
1975	1.46	2.08	1.95	1.41	1.68
1976	1.44	2.01	1.94	NA	1.68
1977	1.44	2.01	1.92	NA	1.67
1978	1.41	2.10	1.98	1.51	1.69
1979	1.42	2.27	2.08	NA	1.75
1980	1.43	2.30	2.21	NA	1.86
1981	1.51	2.38	2.37	1.72	1.87
1982 (Prel.)	1.63	2.48	2.46	NA	1.94
1983 (Est.)	1.69	2.47	2.60	1.61	1.91
1984 (Est.)	1.76	NA	NA	NA	1.86
1985 (Est.)	NA	NA	NA	NA	1.89
	Estimated non-defense R&D expenditures[2] (national currency in billions)				
1971	12.7	15.3	1,520.1	NA	18.1
1972	14.4	17.2	1,777.8	1.0	19.4
1973	15.4	17.9	2,200.2	NA	21.5
1974	18.4	19.6	2,699.8	NA	24.0
1975	21.2	21.6	2,957.7	1.5	26.1
1976	24.2	22.7	3,301.4	NA	28.9
1977	27.1	24.1	3,629.5	NA	32.1
1978	30.2	27.2	4,021.6	2.5	36.6
1979	34.8	31.6	4,556.0	NA	42.3
1980	39.7	34.2	5,216.6	NA	48.8
1981	46.8	36.8	5,949.8	4.4	55.3
1982 (Prel.)	58.1	39.7	6,492.2	NA	59.5
1983 (Est.)	66.6	41.2	7,149.4	4.9	63.2
1984 (Est.)	75.4	NA	NA	NA	68.1
1985 (Est.)	NA	NA	NA	NA	74.6
	Gross national product (national currency in billions)				
1971	873.1	756.0	82,725.8	57.8	1,077.6
1972	961.3	827.2	96,424.0	63.9	1,185.9
1973	1,121.3	920.1	116,636.3	74.2	1,326.4
1974	1,284.4	986.9	138,044.6	84.3	1,434.2
1975	1,452.0	1,034.9	151,797.0	105.2	1,549.2
1976	1,677.8	1,125.0	170,290.0	125.7	1,718.0
1977	1,885.0	1,200.0	188,804.3	143.2	1,918.3
1978	2,141.0	1,290.7	202,708.0	164.6	2,163.9
1979	2,442.0	1,395.3	218,894.0	191.1	2,417.8
1980	2,765.0	1,484.2	235,834.0	229.8	2,631.7
1981	3,110.6	1,543.1	251,259.0	254.8	2,957.8
1982 (Prel.)	3,566.9	1,599.0	263,984.0	278.1	3,069.3
1983 (Est.)	3,935.0	1,671.0	274,639.0	303.2	3,304.8
1984 (Est.)	4,277.9	NA	NA	NA	3,661.3
1985 (Est.)	NA	NA	NA	NA	3,948.2

[1] Gross domestic product

[2] Gross expenditures for performance of R&D including associated capital expenditures, except for the United States, where total capital expenditure data are not available. U.S. estimates for the period 1972-80 show that the inclusion of capital expenditures would have an impact of less than one tenth of one percent of the R&D GNP ratio.

Note: NA = Not available.

Note: The latest data may be preliminary or estimates. The figures for West Germany increased in 1979 in part because of increased coverage of small and medium enterprises not surveyed in 1977.

SOURCE: International Monetary Fund, *International Financial Statistics*, vol. 30 (May 1977), vol. 31 (May 1978); vol. 31 (August 1978); vol. 32 (January 1979); and vol. 33 (August 1980); U.S. Department of Commerce, *International Economic Indicators* (June 1984); OECD, *Science and Technology Indicators Recent Results*, June, 1984 and unpublished statistics; National Science Foundation, *National Patterns of Science and Technology Resources 1984* (NSF 84-311); Robert W. Campbell, *Reference Source of Soviet R&D Statistics, 1950-1978*, National Science Foundation, 1978; Robert W. Campbell, *Soviet R&D Statistics, 1975-1980*, National Science Foundation, 1983; and Robert W. Campbell, *Soviet R&D Statistics, 1970-1983*, National Science Foundation, 1984.

See figure 1-3.

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Appendix table 1-5. National expenditure on research and development[1], by country and source of funds[2]: 1970, 1975, 1979, 1981 and 1983

Country and source	1970	1975	1979	1981	1983	1970	1975	1979	1981	1983
	Million national currency					Million constant 1972[2] dollars				
United States	26,134	35,213	54,933	71,839	86,555	28,613	28,153	33,612	36,728	40,092
Domestic sources	26,134	35,213	54,933	71,839	86,555	28,613	26,153	33,612	36,728	40,092
Business Enterprises	10,444	15,820	26,081	35,941	43,246	11,421	12,579	15,959	18,375	20,081
Government	14,892	18,109	26,815	33,402	40,344	16,316	14,537	16,407	17,087	18,646
Non-profit	337	535	837	973	1,135	370	429	512	498	524
Universities	461	749	1,200	1,523	1,830	506	608	734	780	841
From abroad	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Japan	1,355,505	2,974,573	4,583,630	5,982,356	7,180,000	6,127	8,348	10,658	13,174	15,457
Domestic sources	1,342,048	2,916,051	4,577,044	5,976,214	NA	6,066	8,184	10,643	13,160	NA
Business Enterprises	792,970	1,715,734	2,697,945	3,726,055	NA	3,584	4,815	6,273	8,205	NA
Government	392,012	882,853	1,347,983	1,611,686	NA	1,772	2,478	3,134	3,549	NA
Non-profit	4,887	20,812	16,525	41,857	NA	22	58	38	92	NA
Universities	152,179	296,652	514,591	596,616	NA	688	833	1,197	1,314	NA
From abroad	1,060	3,054	3,586	6,143	NA	5	9	8	14	NA
West Germany	13,903	22,968	33,457	38,351	43,000	5,040	6,077	7,619	8,024	8,332
Domestic sources	13,752	22,580	32,843	37,987	NA	4,985	5,975	7,460	7,947	NA
Business Enterprises	7,419	11,514	18,540	21,863	NA	2,689	3,047	4,222	4,574	NA
Government	6,311	10,898	14,211	15,968	NA	2,288	2,884	3,236	3,341	NA
Non-profit	23	167	92	157	NA	8	44	21	33	NA
Universities	0	0	0	0	NA	0	0	0	0	NA
From abroad	151	388	613	364	NA	55	103	140	76	NA
France	14,955	26,203	44,123	62,471	84,671	3,652	4,192	4,875	5,490	6,025
Domestic sources	14,775	25,847	41,830	59,258	NA	3,606	4,134	4,621	5,207	NA
Business Enterprises	5,465	10,235	19,033	25,498	NA	1,334	1,637	2,103	2,241	NA
Government	8,985	14,467	18,641	23,439	NA	2,194	2,314	2,059	2,060	NA
Non-profit	21	64	267	574	NA	5	10	29	50	NA
Universities	305	1,081	3,889	9,747	NA	74	173	430	857	NA
From abroad	180	356	2,293	3,213	NA	44	57	253	282	NA
United Kingdom[3]	1,069	2,296	3,677	6,135	6,788	4,188	4,862	4,676	5,828	5,716
Domestic sources	1,022	2,182	3,451	5,723	6,418	4,003	4,621	4,390	5,436	5,405
Business Enterprises	453	878	1,554	2,529	2,850	1,776	1,859	1,977	2,402	2,400
Government	548	1,255	1,799	3,015	3,363	2,147	2,657	2,268	2,864	2,832
Non-profit	13	31	61	112	124	50	65	78	106	104
Universities	8	18	37	67	81	30	39	47	64	68
From abroad	47	113	225	411	371	184	240	286	390	312

[1] Gross expenditures for performance of R&D including associated capital expenditures, except for the United States where total capital expenditure data are not available.

[2] Currency conversions based on purchasing power parities. GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

[3] United Kingdom data for 1970 are for fiscal year 1969/70, and 1979 for fiscal year 1978/79.

Note: NA = Not available.

SOURCE: OECD, *Science and Technology Indicators Recent Results*, June 1984. National Science Foundation, *National Patterns of Science and Technology Resources 1984* (NSF 84-311), and OECD, *International Statistical Year, 1983*.

See figure 1-1.

Appendix table 1-6. First degrees conferred by higher educational institutions by major field of study, for selected countries: 1970-1982

Year and country	All Fields	Natural science and engineering	Physical and life sciences and mathematics	Engineering	Agriculture	Other fields
	Thousands					
1970:						
United States	833.3	147.6	91.4	44.8	11.4	685.8
U.S.S.R[1]	630.8	328.5	39.7	230.5	58.3	302.3
France	40.6	16.1	6.9	9.2	—	24.5
Japan	240.9	NA	NA	NA	NA	NA
United Kingdom	51.2	25.4	16.5	8.0	0.9	25.8
West Germany	60.4	NA	3.6	3.7	NA	NA
1975:						
United States	987.9	157.1	100.5	40.1	16.5	830.9
U.S.S.R[1]	713.4	370.9	44.9	272.1	53.9	342.5
France	NA	NA	NA	NA	NA	NA
Japan	313.1	NA	NA	NA	NA	NA
United Kingdom	54.1	27.3	18.7	7.8	0.8	26.8
West Germany	33.7	11.4	5.6	4.8	1.0	22.3
1980:						
United States	1,010.8	177.2	96.8	59.2	21.1	833.6
U.S.S.R[1]	817.3	436.5	52.2	319.8	64.5	380.8
France	52.2	21.5	9.7	11.8	-	30.7
Japan	378.7	98.9	11.6	73.5	13.9	279.8
United Kingdom	66.5	31.8	21.0	9.4	1.4	34.7
West Germany	46.3	14.9	6.5	6.7	1.7	31.4
1981:						
United States	1,019.2	182.7	98.5	64.1	20.2	836.5
U.S.S.R[1]	831.2	446.2	52.6	327.0	67.0	385.0
France	NA	NA	8.4	NA	NA	NA
Japan	NA	NA	NA	NA	NA	NA
United Kingdom	NA	NA	NA	NA	NA	NA
West Germany	NA	NA	5.4	5.4	NA	NA
1982:						
United States	1,036.6	189.3	102.3	67.8	19.2	847.3
U.S.S.R[1]	840.8	451.3	52.1	330.3	68.9	389.5
France	NA	NA	NA	NA	NA	NA
Japan	382.5	98.9	11.8	73.6	13.6	158.0
United Kingdom	66.2	28.2	16.6	10.3	1.3	38.0
West Germany	50.6	17.1	8.1	7.1	1.9	33.5

[1] Figures for the Soviet Union are estimates made to approximate the U.S. definitions.

SOURCES: Catherine P. Ailes and Francis W. Rushing, *The Science Race: Training and Utilization of Scientists and Engineers, U.S. and U.S.S.R.* (New York: Crane Russak, 1982) p. 68. Updated U.S. and U.S.S.R. data for 1980-82 provided by Catherine P. Ailes; Japanese data from *Statistical Abstract of Education, Science and Culture*, Ministry of Education, Science and Culture (Tokyo, Japan 1983) p. 96; West German data from Der Bundesminister fur Bildung und Wissenschaft, *Grund- und Struktur Daten, 1982/83* (Bonn, West Germany, 1982) p. 158.

See figure 1-5.

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Appendix table 1-7. U.S. and world scientific and technical articles[1], by field: 1972-82

Field[2]	1973	1974	1975	1976	1977	1978	1979	1980	1981[3]	1982[3]
	U.S. articles as a percent of all articles									
All fields	38	38	37	37	37	38	37	37	35	35
Clinical medicine	43	43	43	43	43	43	43	43	41	41
Biomedicine	39	38	39	39	39	39	40	40	39	40
Biology	46	46	45	44	42	42	43	42	37	38
Chemistry	23	22	22	22	22	21	21	21	20	21
Physics	33	33	32	31	30	31	30	30	28	27
Earth and space sciences	47	47	44	46	45	45	45	42	42	42
Engineering and technology	42	42	41	41	40	39	41	39	38	38
Mathematics	48	46	44	43	41	40	40	40	36	37
	U.S. articles[4]									
All fields	103,777	100,066	97,278	99,970	97,854	99,207	99,377	98,394	134,940	135,953
Clinical medicine	32,638	31,691	31,334	32,920	33,516	34,966	33,975	34,612	49,082	49,458
Biomedicine	16,115	15,607	15,901	16,271	16,197	16,611	17,649	17,582	22,029	22,892
Biology	11,150	10,700	10,400	10,573	9,904	9,663	10,553	9,594	15,070	15,199
Chemistry	10,474	9,867	9,222	9,337	8,852	9,266	9,182	9,250	10,946	11,820
Physics	11,721	11,945	11,363	11,502	10,995	11,015	10,995	11,415	13,111	13,315
Earth and space sciences	5,591	5,371	4,975	5,537	5,197	5,043	5,167	4,832	7,421	7,220
Engineering and technology	11,955	11,088	10,431	10,346	10,061	9,694	9,018	8,461	13,282	12,284
Mathematics	4,134	3,797	3,652	3,484	3,112	2,949	2,838	2,648	4,000	3,765
	All articles									
All fields	271,513	265,130	260,908	267,354	263,700	270,128	267,953	269,556	382,327	383,697
Clinical medicine	76,209	74,509	73,485	76,699	77,597	81,209	78,827	80,533	119,477	120,926
Biomedicine	41,155	40,632	41,244	41,891	41,388	42,968	43,631	44,267	55,787	57,585
Biology	24,047	23,414	23,260	23,905	23,757	23,176	24,734	22,838	40,328	39,875
Chemistry	45,004	44,529	42,502	42,773	40,734	43,550	43,273	44,448	55,789	56,630
Physics	35,854	35,708	35,104	36,902	36,057	35,515	36,700	37,944	46,913	48,677
Earth and space sciences	11,977	11,479	11,356	12,011	11,531	11,224	11,596	11,395	17,656	17,241
Engineering and technology	28,617	26,600	25,664	25,146	25,003	24,588	22,182	21,459	35,248	32,598
Mathematics	8,639	8,259	8,293	8,127	7,573	7,298	7,011	6,673	11,128	10,165

[1] Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[2] See appendix table 1-8 for the subfields included in these fields.

[3] Uses over 3,500 of the influential journals carried on the 1981 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information.

[4] When an article is written by researchers from more than one country, that article is prorated across the countries involved. For example, if a given article has several authors from France and the United States it is split on the basis of these countries regardless of the number of organizations represented by the authors.

Note: Detail may not add to totals because of rounding.

SOURCE: Computer Horizons, Inc., unpublished data.

See table 1-1 in text.

Appendix table 1-8. Publications in the fields and subfields of international scientific literature: 1982

Field and subfield	Number of articles	
	World	United States
Clinical medicine	120,926	49,458
General & internal medicine	18,772	5,748
Allergy	695	245
Anesthesiology	1,347	445
Cancer	5,601	2,860
Cardiovascular system	5,040	2,482
Dentistry	2,539	1,162
Dermatology & venereal diseases	2,874	1,025
Endocrinology	4,547	1,716
Fertility	1,292	544
Gastroenterology	1,901	660
Geriatrics	707	494
Hematology	2,240	805
Immunology	7,396	3,249
Obstetrics & gynecology	2,263	975
Neurology & neurosurgery	9,587	4,144
Ophthalmology	2,602	1,112
Orthopedics	1,380	564
Arthritis & rheumatism	857	313
Otorhinolaryngology	1,591	790
Pathology	2,703	958
Pediatrics	2,959	1,258
Pharmacology	10,893	3,926
Pharmacy	4,056	1,148
Psychiatry	2,466	1,494
Radiology & nuclear medicine	5,038	2,615
Surgery	5,388	2,928
Tropical medicine	711	151
Urology	1,778	838
Nephrology	654	276
Veternary medicine	5,910	1,907
Addictive diseases	451	306
Hygiene & public health	2,639	1,453
Miscellaneous clinical medicine	589	292
Biomedicine	57,585	22,892
Physiology	3,908	1,686
Anatomy & morphology	762	273
Embryology	975	434
Genetics & heredity	4,520	1,586
Nutrition & dietetics	1,841	870
Biochemistry & molecular biology	19,166	7,698
Biophysics	1,153	336
Cell biology, cytology & histology	5,256	2,075
Microbiology	4,572	1,586
Virology	1,933	822
Parasitology	1,219	474
Biomedical engineering	1,381	518
Microscopy	581	166
Miscellaneous biomedicine	1,529	753
General biomedicine	8,790	3,617
Biology	39,875	15,199
General biology	1,777	613
General zoology	2,074	342
Entomology	2,693	1,286
Miscellaneous zoology	3,094	1,278
Marine biology & hydrobiology	3,427	1,205
Botany	9,581	3,459
Ecology	2,751	1,258
Agriculture & food science	10,235	4,060
Dairy animal science	3,300	1,322
Miscellaneous biology	943	372
Chemistry	56,630	11,820
Analytical chemistry	5,636	1,609
Organic chemistry	8,123	2,016
Inorganic & nuclear chemistry	4,520	784
Applied chemistry	2,927	456
General chemistry	17,348	2,853
Polymers	4,600	1,114
Physical chemistry	13,475	2,988
Physics	48,677	13,315
Chemical physics	5,711	2,076
Solid state physics	7,276	1,740
Fluids & plasmas	1,084	560
Applied physics	12,123	3,257
Acoustics	1,130	472
Optics	2,975	988
General physics	14,231	2,626
Nuclear & particle physics	3,055	1,246
Miscellaneous physics	1,092	350
Earth & space science	17,241	7,220
Anatomy & astrophysics	4,418	2,006
Meteorology & atmospheric science	1,449	853
Geology	2,791	1,054
Earth & planetary science	7,171	2,758
Geography	54	10
Oceanography & limnology	1,358	539
Engineering and technology	32,598	12,284
Chemical engineering	3,380	1,672
Mechanical engineering	3,092	1,077
Civil engineering	2,106	1,332
Electrical engineering & electronics	7,904	2,652
Miscellaneous engineering & technology	779	248
Industrial engineering	48	34
General engineering	1,304	268
Metals & metallurgy	4,309	850
Materials science	3,434	1,260
Nuclear technology	2,417	995
Aerospace technology	839	520
Computers	2,127	969
Library & information science	209	119
Operations research & management science	651	290
Mathematics	10,165	3,765
Probability and statistics	1,611	833
Applied mathematics	1,787	735
General mathematics	5,338	1,574
Miscellaneous mathematics	1,430	623
All fields	383,697	135,953

SOURCE: Computer Horizons, Inc., unpublished data.

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Appendix table 1-9. Relative citation ratios[1] for U.S. articles[2], by field: 1973-80

Field[3]	1973	1974	1975	1976	1977	1978	1979	1980
World citations to U.S.:								
All fields	1.40	1.41	1.42	1.41	1.43	1.43	1.41	1.40
Clinical medicine	1.36	1.36	1.36	1.35	1.35	1.36	1.33	1.35
Biomedicine	1.42	1.43	1.41	1.41	1.41	1.37	1.36	1.40
Biology	1.08	1.11	1.11	1.10	1.14	1.13	1.14	1.15
Chemistry	1.66	1.67	1.70	1.69	1.74	1.76	1.74	1.75
Physics	1.53	1.53	1.54	1.57	1.57	1.53	1.57	1.54
Earth and space sciences	1.38	1.39	1.45	1.38	1.42	1.42	1.44	1.44
Engineering and technology	1.28	1.28	1.26	1.23	1.27	1.31	1.28	1.24
Mathematics	1.24	1.23	1.23	1.21	1.26	1.32	1.25	1.22
Non-U.S. citations to U.S.:								
All fields	1.03	1.01	1.01	0.99	0.98	0.94	0.90	0.85
Clinical medicine	1.02	1.01	1.00	0.98	0.96	0.93	0.89	0.82
Biomedicine	1.09	1.06	1.04	1.03	1.01	0.94	0.93	0.92
Biology	0.69	0.68	0.66	0.64	0.64	0.60	0.60	0.55
Chemistry	1.20	1.16	1.17	1.13	1.14	1.13	1.03	1.01
Physics	1.18	1.15	1.14	1.14	1.12	1.05	1.08	0.99
Earth and space sciences	1.06	1.06	1.10	1.03	1.04	1.05	1.01	0.96
Engineering and technology	0.90	0.83	0.80	0.76	0.75	0.76	0.71	0.61
Mathematics	0.89	0.87	0.83	0.79	0.80	0.84	0.73	0.64

[1] A citation ratio of 1.00 reflects no over- or under-citing of the U.S. scientific and technical literature, whereas a higher ratio indicates a greater influence, impact or utility than would have been expected from the number of U.S. articles for that year. For example, the U.S. chemistry literature for 1973 received 66 percent more citations from the world's chemistry articles published in 1973.

[2] Based on the articles, notes and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. For the size of this data base, see appendix table 1-7.

[3] See appendix table 1-8 for a description of the subfields included in these fields.

SOURCE: Computer Horizons, Inc., unpublished data.

See table 1-2 in text.

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Appendix table 1-10. External patent applications by inventors from selected countries: 1969-1982

Year	United States	Japan	West Germany	France	United Kingdom
1969	131,287	23,815	72,028	26,807	37,275
1970	123,724	26,568	70,137	24,422	33,463
1971	116,052	28,142	70,798	25,586	31,700
1972	119,984	25,760	70,636	27,887	33,324
1973	116,581	31,945	74,073	27,793	33,075
1974	102,711	33,463	67,335	22,821	28,968
1975	93,042	27,666	60,810	23,433	24,402
1976	93,356	29,340	58,310	23,356	24,185
1977	95,749	29,047	59,517	22,967	23,202
1978	85,352	30,182	53,657	22,073	21,286
1979	80,744	33,766	49,539	19,276	18,701
1980	79,078	35,945	48,650	18,839	17,400
1981	73,895	34,903	42,323	15,533	16,890
1982	65,335	36,901	38,985	15,498	16,144

SOURCE: World Industrial Property Organization, unpublished statistics; OECD, unpublished statistics.

See figure 1-6.

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Appendix table 1-11. Real gross domestic product per employed person, for selected countries: 1950-1983

Year	United States	Japan	West Germany	France	United Kingdom	Canada
	Constant 1972 dollars[1]					
1950	$8.794	$1.536	$3.485	$3.858	$4.716	$7.416
1955	10,028	2,113	4,784	4,713	5,234	8.786
1960	10,733	2,883	6,463	5,974	5,802	9.459
1965	12,503	4,365	8,002	7,755	6,526	10.894
1970	13,184	6,852	9,884	9,687	7,510	12,110
1971	13,563	7,120	10,129	10,165	7,839	12,668
1972	13,911	7,731	10,581	10,709	7,932	13,031
1973	14,203	8,198	10,988	11,144	8,422	13,356
1974	13,827	8,144	11,193	11,416	8,256	13,283
1975	13,856	8,364	11,329	11,549	8,207	13,206
1976	14,133	8,725	12,049	12,065	8,475	13,601
1977	14,391	9,063	12,438	12,335	8,640	13,727
1978	14,475	9,403	12,741	12,762	8,912	13,703
1979	14,423	9,764	13,104	13,188	9,018	13,690
1980	14,315	10,142	13,208	13,342	8,894	13,467
1981	14,537	10,483	13,262	13,482	9,065	13,484
1982 (Prel.)	14,400	10,691	13,345	13,742	9,409	13,289
1983 (Est.)	14,712	10,836	13,805	13,875	9,715	13,540
	Index: United States = 100					
1950	100	17.5	39.6	43.9	53.6	84.3
1955	100	21.1	47.7	47.0	52.2	87.6
1960	100	26.9	60.2	55.7	54.1	88.1
1965	100	34.9	64.0	62.0	52.2	87.1
1970	100	52.0	75.0	73.5	57.0	91.9
1971	100	52.5	74.7	74.9	57.8	93.4
1972	100	55.6	76.1	77.0	57.0	93.7
1973	100	57.7	77.4	78.5	59.3	94.0
1974	100	58.9	81.0	82.6	59.7	96.1
1975	100	60.4	81.8	83.4	59.2	95.3
1976	100	61.7	85.3	85.4	60.0	96.2
1977	100	63.0	86.4	85.7	60.0	95.4
1978	100	65.0	88.0	88.2	61.6	94.7
1979	100	67.7	90.9	91.4	62.5	94.9
1980	100	70.8	92.3	93.2	62.1	94.1
1981	100	72.1	91.2	92.7	62.4	92.8
1982 (Prel.)	100	74.2	92.7	95.4	65.3	92.3
1983 (Est.)	100	73.7	93.8	94.3	66.0	92.0

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars. International price weights are used in currency conversions to enable cross-country comparisons.

SOURCE: Department of Labor, Bureau of Labor Statistics, Office of Productivity and Technology, *Comparative Real Gross Domestic Product, Real GDP per Capita, and Real GDP per Employed Person, 1950-1983*, May 1984.

See figure 1-7.

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Appendix table 1-12. U.S. exports and sales of technology-intensive products, by field: 1972-81

Product groups	1972	1975	1977	1980	1981
	Exports as a percent of output				
All technology-intensive products[1]	23.0	34.6	33.1	34.9	35.4
Industrial inorganic chemicals	19.6	26.3	26.5	38.5	38.6
Plastic materials, synthetics	17.8	26.0	26.1	51.4	49.0
Drugs	7.1	9.7	9.7	13.6	13.8
Agricultural chemicals	20.1	29.6	26.5	55.7	43.2
Engines and turbines	38.3	63.8	49.3	66.5	64.9
Office and computing machines	33.1	41.0	36.7	45.8	44.4
Electrical machinery and equipment	10.7	50.3	49.4	70.6	73.1
Radio and tv receiving equipment	12.1	21.1	15.5	22.9	23.3
Communications equipment	10.4	17.5	16.7	13.4	13.5
Aircraft and parts	39.5	56.2	46.2	51.1	57.4
Engineering & scientific instrument	40.5	54.7	51.2	48.9	44.5
	U.S. exports in million dollars				
All technology-intensive products[1]	$13,299	$26,178	$30,796	$54,240	$59,856
Industrial inorganic chemicals	656	1,369	1,717	3,378	3,579
Plastic materials, synthetics	879	1,436	2,045	5,021	5,003
Drugs	433	778	967	1,839	2,050
Agricultural chemicals	350	1,346	1,009	3,154	2,683
Engines and turbines	1,110	2,192	2,447	4,367	4,794
Office and computing machines	1,623	2,640	3,645	8,320	9,395
Electrical machinery and equipment	566	3,372	4,423	8,493	9,781
Radio and tv receiving equipment	265	408	478	865	867
Communications equipment	1,437	2,855	3,917	5,305	5,862
Aircraft and parts	3,601	7,194	6,805	14,104	16,142
Engineering & scientific instrument	1,379	2,588	3,343	4,866	4,949
	Value added by manufacture in million dollars				
All technology-intensive products[1]	57,700	75,663	93,109	155,266	169,039
Industrial inorganic chemicals	3,343	5,213	6,487	8,773	9,274
Plastic materials, synthetics	4,935	5,525	7,843	9,760	10,211
Drugs	6,131	8,030	9,940	13,490	14,879
Agricultural chemicals	1,737	4,546	3,808	5,658	6,217
Engines and turbines	2,900	3,434	4,960	6,567	7,382
Office and computing machines	4,905	5,525	7,843	9,760	10,211
Electrical machinery and equipment	5,278	6,701	8,950	12,038	13,386
Radio and tv receiving equipment	2,183	1,934	3,078	3,772	3,728
Communications equipment	13,759	16,308	23,390	39,484	43,521
Aircraft and parts	9,124	12,801	14,732	27,622	28,144
Engineering & scientific instrument	3,405	4,730	6,529	9,949	11,123

[1] Technology-intensive products are defined as those for which R&D expenditures exceed 2.36 percent of value-added.

SOURCE: OECD, unpublished data, and Bureau of the Census, *Statistical Abstract of the United States*, 1984.

See figure 1-8.

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Appendix table 1-13. U.S. trade in high-technology[1] and other manufacturing product groups: 1970-84

	High technology			Non-high technology		
	Exports	Imports	Balance	Exports	Imports	Balance
	Billion constant 1972 dollars[2]					
1970[3]	11.26	4.59	6.67	20.78	24.93	-4.16
1971[3]	11.87	5.10	6.77	19.79	28.54	-8.75
1972[3]	11.90	6.30	5.60	21.80	33.70	-11.90
1973[3]	15.04	7.47	7.57	27.23	37.64	-10.40
1974	18.68	8.52	10.17	36.50	43.19	-6.69
1975	18.20	7.55	10.65	38.24	36.17	2.07
1976	19.34	9.97	9.37	38.99	42.62	-3.63
1977	19.49	10.92	8.57	37.77	47.55	-9.78
1978	22.93	13.34	9.59	39.58	57.63	-18.06
1979	26.39	13.76	12.63	47.68	58.96	-11.27
1980	30.40	15.52	14.88	53.24	58.39	-5.15
1981	30.60	17.12	13.49	51.46	59.14	-7.68
1982[3]	27.75	16.45	11.31	43.31	56.19	-12.88
1983[3]	27.70	18.97	8.73	37.11	60.32	-23.21
1984[3]	29.08	26.29	2.79	38.59	77.53	-38.94

[1] U.S. Department of Commerce DOC-3 definitions.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

[3] Estimated.

SOURCE: U.S. Department of Commerce, International Trade Administration, *U.S. Trade Performance in 1983 and Outlook* (June, 1984), and U.S. Department of Commerce, unpublished data.

See figure 1-9

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Appendix table 1-14. Trade in technology-intensive[1] products, by country: 1970-82

	Total	United States	Canada	Japan	France	West Germany	United Kingdom
	High-technology imports in million constant 1972 dollars[2]						
1970	21,338	5,861	2,976	2,017	3,304	4,140	3,043
1971	22,749	6,371	3,085	2,026	3,441	4,538	3,288
1972	26,983	7,917	3,597	2,193	4,222	5,105	3,948
1973	34,363	9,570	4,326	2,861	5,567	6,665	5,374
1974	38,984	10,298	4,956	3,618	6,510	7,475	6,127
1975	36,293	9,219	4,525	2,889	6,198	7,791	5,671
1976	42,366	12,199	4,804	3,185	7,171	9,127	5,879
1977	46,167	13,299	4,926	3,297	7,532	10,359	6,755
1978	56,277	16,744	5,502	3,927	8,770	12,427	8,908
1979	64,484	17,271	6,163	4,801	10,504	14,860	10,883
1980	70,321	18,728	6,417	5,378	11,878	15,843	12,077
1981	66,593	20,169	7,023	5,284	9,947	13,962	10,209
1982	63,177	19,787	5,967	4,888	9,220	13,267	10,049
	High-technology exports in million constant 1972 dollars[2]						
1970	35,243	12,527	2,079	5,088	3,276	7,774	4,499
1971	37,699	13,012	2,114	5,793	3,511	8,200	5,068
1972	42,110	13,299	2,374	7,180	4,134	9,537	5,586
1973	53,089	16,803	2,471	8,876	5,425	13,030	6,484
1974	64,311	21,246	2,627	10,525	6,534	15,748	7,631
1975	62,735	20,810	2,496	9,870	7,124	14,294	8,141
1976	69,366	21,808	2,984	12,733	7,830	16,021	7,990
1977	74,628	21,990	3,012	14,520	8,386	17,652	9,069
1978	87,237	25,475	3,386	17,359	9,693	20,297	11,025
1979	97,316	29,161	3,823	17,420	11,902	22,428	12,581
1980	107,508	33,468	4,054	20,156	11,926	22,847	15,056
1981	101,594	33,364	4,406	22,684	10,239	19,207	11,694
1982	94,487	30,663	4,050	19,642	10,080	18,736	11,315

[1] Technology-intensive products are defined as those for which R&D expenditures exceed 2.36 percent of value-added.

[2] Currency conversion based on purchasing power parities. GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: OECD, unpublished data.

See figure 1-14.

Appendix table 1-15. U.S. direct investment position abroad in manufacturing, for selected nations and industry groups: 1966-83

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
	Million constant 1972 dollars[1]																	
Total manufacturing	$27,019	$28,843	$30,482	$32,644	$33,952	$35,787	$38,325	$41,957	$44,466	$44,428	$46,215	$44,283	$46,316	$48,121	$49,973	$47,232	$43,679	$41,852
Total major countries	17,641	18,300	18,988	20,263	20,924	22,001	23,533	25,674	26,575	26,214	27,273	26,096	26,982	27,717	25,804	26,436	24,532	23,737
Canada	8,725	8,929	9,129	9,683	9,810	9,899	10,491	11,116	11,688	11,679	12,064	10,564	10,461	10,643	10,580	10,129	9,511	9,218
France	1,514	1,594	1,579	1,687	1,981	2,195	2,441	2,783	2,979	3,056	3,020	3,006	3,109	3,138	3,316	2,822	2,302	1,963
West Germany	2,277	2,474	2,604	2,974	2,925	3,236	3,637	4,200	4,183	4,236	5,067	5,187	5,550	5,247	5,413	5,138	4,858	4,601
United Kingdom	4,648	4,744	5,039	5,176	5,368	5,653	5,779	6,252	6,405	6,006	5,844	5,934	6,304	6,991	4,830	6,694	6,192	6,065
Japan	477	559	638	743	840	1,019	1,185	1,323	1,321	1,238	1,278	1,405	1,558	1,698	1,666	1,654	1,669	1,890
Other countries	9,379	10,543	11,494	12,382	13,028	13,786	14,792	16,284	17,891	18,214	18,[illegible]42	18,188	19,335	20,404	24,168	20,796	19,147	18,115
Total chemical products	5,003	5,744	6,140	6,382	6,413	6,790	7,253	7,957	8,839	8,830	9,206	8,471	9,300	10,144	10,586	10,315	9,749	9,390
Total major countries	2,708	2,874	2,968	3,027	3,057	3,316	3,512	3,916	4,198	4,175	4,319	3,880	4,321	4,870	4,927	4,780	4,497	4,259
Canada	1,378	1,450	1,480	1,494	1,443	1,513	1,583	1,671	1,781	1,803	1,860	1,606	1,713	1,815	1,907	1,901	1,915	1,832
France	214	272	274	306	327	344	390	428	472	– 471	482	494	502	562	588	533	445	371
West Germany	233	253	290	298	323	389	425	547	600	612	691	[illegible]15	773	853	841	835	785	771
United Kingdom	770	769	766	742	768	853	870	985	1,061	1,003	1,003	833	971	1,230	1,199	1,119	978	903
Japan	113	130	159	186	197	218	244	285	284	286	283	332	362	410	392	392	374	382
Other countries	2,294	2,870	3,172	3,355	3,356	3,474	3,741	4,042	4,641	4,655	4,887	4,591	4,979	5,274	5,660	5,535	5,253	5,131
Total machinery	6,557	6,900	7,252	8,079	8,575	9,301	10,096	11,169	12,158	12,398	12,914	8014	8,647	12,804	13,099	12,399	11,220	10,854
Total major countries	4,670	4,885	4,910	5,259	5,419	6,314	6,819	7,337	7,728	7,751	7,896	5,662	6,088	7,852	7,983	7,356	6,736	6,559
Canada	1,752	1,801	1,827	2,008	1,939	1,970	2,111	2,199	2,331	2,418	2,453	1,108	1,147	1,772	1,772	1,850	1,761	1,835
France	577	560	552	580	678	775	834	956	1,038	1,125	1,062	1,127	1,220	1,351	1,463	1,230	917	774
West Germany	685	737	1,081	1,044	1,064	1,221	1,388	1,591	1,694	1,670	1,841	1,409	1,548	1,961	1,900	1,634	1,458	1,355
United Kingdom	1,367	1,450	1,450	1,627	1,739	1,816	1,853	1,899	1,993	1,912	1,889	1,409	1,459	2,006	2,096	1,920	1,878	1,783
Japan	289	336	(2)	(2)	(2)	532	633	692	673	626	651	608	715	762	753	722	722	812
Other countries	1,886	2,015	2,342	2,821	3,156	2,987	3,277	3,832	4,431	4,647	5,019	2,352	2,559	4,952	5,116	5,043	4,484	4,295

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

[2] These data are withheld by the U.S. Commerce Department to avoid disclosure of data for individual companies.

SOURCES: U.S Department of Commerce, Bureau of Economic Analysis, *Selected Data on U.S. Direct Investment Abroad, 1966-78,* 1980, and *Survey of Current Business.* (February 1981), pp. 50-51, *Survey of Current Business* (August 1981), pp. 31-32, *Survey of Current Business* (August 1982), pp. 21-22, *Survey of Current Business* (August 1983), pp. 23-24, *Survey of Current Business* (August 1983), pp. 28-29.

See figures 1-10 and 1-11.

Appendix table 1-16. U.S. receipts and payments of royalties and fees associated with unaffiliated foreign residents: 1972-83

Years	All countries	Canada	West Germany	France	United Kingdom	Other Europe	Japan	Other countries
	Million constant 1972 dollars[1]							
Receipts:								
1972	$655	$38	$56	$42	$63	$150	$240	$66
1973	673	30	60	41	71	114	258	99
1974	653	33	68	40	62	119	216	115
1975	602	30	64	37	63	120	174	113
1976	621	34	63	43	54	119	186	122
1977	740	30	66	34	59	150	196	206
1978	784	41	79	31	62	137	228	207
1979	737	26	67	33	62	137	210	201
1980	731	38	81	81	63	67	226	175
1981 (Prel.)	764	35	52	68	61	142	217	189
1982 (Est.)	760	32	52	59	59	131	230	197
1983 (Est.)	732	26	80	37	58	120	232	181
Payments:								
1972	139	6	29	13	44	35	6	6
1973	166	6	35	15	50	39	12	9
1974	162	6	30	12	58	37	10	8
1975	148	7	25	12	60	32	7	4
1976	143	7	26	11	58	26	10	5
1977	187	6	22	10	51	27	11	59
1978	184	7	18	11	56	31	10	52
1979	189	10	24	10	57	31	9	47
1980	166	10	34	17	54	31	11	9
1981 (Prel.)	148	7	22	15	51	27	19	8
1982 (Est.)	129	5	17	11	45	27	15	9
1983 (Est.)	131	5	17	11	42	29	18	10

[1] GNP implicit price deflator used to convert current dollars to constant 1972 dollars.

SOURCE: U.S. Department of Commerce, *Survey of Current Business* (June issues, 1974, 1975, 1977, 1981-84) and U.S. Department of Commerce, Bureau of Economic Analysis, unpublished data.

See figure 1-12.

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Appendix table 1-17. Receipts and payments of royalties and fees, by country: 1972-82

Year	United States	Japan	West Germany	United Kingdom	France
	Million constant 1972 dollars[1]				
Receipts:					
1972	$2,566	$181	$205	$380	$242
1973	2,857	195	172	430	266
1974	2,941	182	192	459	346
1975	3,186	197	201	412	318
1976	3,086	233	188	493	371
1977	3,215	246	193	480	415
1978	3,531	306	205	480	427
1979	3,517	325	207	460	406
1980	3,709	380	222	406	389
1981	3,517	386	258	432	433
1982	3,325	400	272	445	438
1983	3,497	519	292	519	445
Payments:					
1972	294	745	443	380	368
1973	364	875	430	411	386
1974	301	508	427	454	421
1975	376	500	477	403	381
1976	326	495	451	427	470
1977	310	502	471	420	453
1978	406	481	460	419	461
1979	468	524	448	382	474
1980	427	571	457	355	465
1981	355	572	558	357	473
1982	NA	612	540	368	511
1983	NA	601	583	407	492
Ratio of receipts to payments:					
1972	8.73	0.24	0.46	1.00	0.66
1973	7.85	0.22	0.40	1.05	0.69
1974	9.78	0.36	0.45	1.01	0.82
1975	8.47	0.39	0.42	1.02	0.83
1976	9.45	0.47	0.42	1.16	0.79
1977	10.38	0.49	0.41	1.14	0.91
1978	8.71	0.64	0.45	1.14	0.93
1979	7.52	0.62	0.46	1.21	0.86
1980	8.68	0.66	0.49	1.15	0.84
1981	9.90	0.67	0.46	1.21	0.91
1982	NA	0.65	0.50	1.21	0.86
1983	NA	0.86	0.50	1.27	0.90

[1] Currency conversions based on purchasing power parities. GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

Note: NA = Not available

SOURCE: Organisation for Economic Cooperation and Development, unpublished data.

See figures 1-13 and 1-14.

Science Indicators—1985

Appendix table 1-18. Industrial research and development in selected countries, by industry: 1975 and 1981

Industries	Total	United States	Japan	West Germany	United Kingdom	France	Canada	Italy
	Million constant 1972 dollars[1]							
	1975[2]							
Total	$32,540	$18,642	$4,507	$3,506	$2,548	$2,326	$407	$604
Sub-total electrical group	7,658	4,058	1,085	1,047	557	600	138	172
Chemicals	3,716	1,387	665	1,002	300	233	31	98
Drugs	1,483	780	279	NA	165	130	17	113
Petroleum refineries	795	551	50	21	38	84	32	19
Aerospace	6,009	4,542	NA	332	610	471	40	15
Motor vehicle	3,272	1,860	575	405	184	247	NA	NA
Other transportation	390	72	274	2	33	9	NA	NA
Ferrous metals	613	171	262	60	59	35	10	17
Non-ferrous metals	386	181	76	32	17	33	33	14
Fabricated metal products	417	258	87	14	21	30	7	NA
Instruments	1,239	933	106	74	46	32	4	45
Office machines and computer	2,111	1,765	90	NA	106	138	14	NA
Other machinery	1,822	776	339	413	153	88	29	23
Food, drink and tobacco	584	266	135	23	103	33	17	6
Textiles and clothing	250	56	66	15	58	25	3	28
Rubber and plastics	630	371	83	32	21	87	3	33
Stone, clay and glass	413	185	122	23	37	37	4	4
Paper and printing	289	198	56	8	17	7	NA	2
Wood, cork and furniture	99	70	NA	2	3	2	21	NA
Other manufacturing	363	163	156	NA	18	6	3	16
	1981[3]							
Total	44,938	17,619	7,625	4,355	1,801	2,398	475	949
Sub-total electrical group	9,472	3,284	2,027	1,113	336	591	152	158
Chemicals	5,309	1,609	910	1,172	297	300	38	95
Drugs	2,770	1,058	495	NA	205	254	17	159
Petroleum refineries	1,805	912	90	30	35	126	76	32
Aerospace	3,207	1,763	3	75	113	134	76	72
Motor vehicle	6,015	2,162	1,206	727	165	377	NA	187
Other transportation	274	41	170	9	17	13	NA	2
Ferrous metals	877	213	379	66	44	35	9	14
Non-ferrous metals	499	147	153	26	13	36	26	17
Fabricated metal products	750	279	149	91	30	39	8	NA
Instruments	2,838	1,526	291	95	39	30	6	10
Office machines and computer	3,627	1,971	262	NA	110	111	9	78
Other machinery	3,358	1,167	545	697	138	111	25	31
Food, drink and tobacco	972	326	229	60	107	42	20	9
Textiles and clothing	335	59	146	21	41	21	4	10
Rubber and plastics	940	306	223	79	14	113	6	31
Stone, clay and glass	656	211	192	52	36	41	4	4
Paper and printing	545	290	48	19	19	8	NA	2
Wood, cork and furniture	184	85	29	17	2	4	NA	NA
Other manufacturing	504	211	77	8	40	15	NA	37

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[1] Currency conversion based on purchasing power parities. GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

[2] Total business sector expenditures.

[3] Privately-financed business sector expenditures.

SOURCE: National Science Foundation, *Research and Development in Industry, 1981* (NSF 83-325), OECD, *International Statistical Year 1981*, and OECD, unpublished data.

See table 1-3 in text.

Appendix table 1-19. U. S. patents granted, by country of residence of inventor and product fields: 1975 and 1981

Patents	Seven country Total	United States	Japan	West Germany	United Kingdom	France	Canada	Italy
	1975							
Total[1]	60,391	42,191	6,072	5,456	2,668	2,152	1,131	704
Electrical & electronic machinery	10,178	7,097	1,231	763	447	403	158	91
Inorganic & organic chemistry	8,809	5,478	921	1,155	510	438	121	186
Petroleum & natural gas extraction & refining	672	588	19	11	15	17	21	1
Aircraft & parts	711	452	94	77	49	27	7	4
Motor vehicle and equipment	1,327	870	161	139	60	56	30	12
Other transportation equipment	842	571	77	77	44	31	31	8
Primary ferrous products	308	182	49	36	16	13	7	7
Primary & secondary non-ferrous products	361	219	61	38	16	11	14	3
Fabricated metal products	5,313	4,120	302	383	176	169	108	47
Professional & scientific instruments	7,165	4,986	1,025	533	263	192	79	58
Machinery, except electrical	12,693	8,788	1,021	1,365	591	444	313	171
Office computing & accounting machines	1,406	993	192	103	47	43	6	26
Food and kindred products	472	372	35	20	20	12	9	3
Textile mill products	402	244	53	58	25	16	2	2
Rubber & miscellaneous plastic products	2,551	1,757	290	238	124	85	35	28
Stone, clay, glass & concrete products	1,038	769	91	78	73	34	12	7
Other patents	6,143	4,705	450	382	192	161	178	50
	1981							
Total[1]	39,232	34,223	6,188	3,967	1,366	1,264	794	469
Electrical & electronic machinery	6,739	6,154	1,335	512	198	272	173	55
Inorganic & organic chemistry	6,135	4,420	797	829	283	244	88	142
Petroleum & natural gas extraction & refining	578	647	15	18	8	19	12	1
Aircraft & parts	377	332	83	53	22	21	8	2
Motor vehicle and equipment	729	544	190	98	33	31	14	4
Other transportation equipment	331	338	43	36	15	13	10	4
Primary ferrous products	177	111	53	15	7	5	6	0
Primary & secondary non-ferrous products	214	155	50	17	13	6	5	1
Fabricated metal products	3,117	3,168	304	269	96	98	78	27
Professional & scientific instruments	5,027	4,518	1,077	438	146	116	89	45
Machinery, except electrical	7,468	6,568	907	972	276	237	200	112
Office computing & accounting machines	945	977	282	74	21	17	16	15
Food and kindred products	353	282	40	17	17	15	15	2
Textile mill products	299	202	56	36	11	17	3	2
Rubber & miscellaneous plastic products	2,040	1,565	338	207	65	50	24	19
Stone, clay, glass & concrete products	930	728	153	82	50	27	10	9
Other patents	3,773	3,514	465	294	105	76	43	29

[1] The total number of patents granted is somewhat greater than the numbers reported here due to rounding errors introduced during the process of allocating patents to multiple industrial groups.

SOURCE: U.S. Patent and Trademark Office, Office of Technology Assessment and Forecast, unpublished data.

Appendix table 1-20. Patent activity in selected countries, for selected technologies: 1975-77 and 1980-82

Technology group	Total		United States		Japan		West Germany		France		United Kingdom		Other	
	1975-77	1980-82	1975-77	1980-82	1975-77	1980-82	1975-77	1980-82	1975-77	1980-82	1975-77	1980-82	1975-77	1980-82
	Patents granted													
All technologies	1,197,447	1,240,822	320,338	284,670	176,278	251,219	736,448	212,129	81,292	73,576	83,879	77,832	299,212	341,396
Robotics	481	1,093	134	148	44	144	72	150	48	72	15	43	168	536
Lasers	2,814	4,289	1,326	1,295	312	1,568	357	421	282	270	134	211	403	524
Microbiology-enzymology	1,760	9,581	361	2,463	820	3,265	231	1,172	47	422	145	602	156	1,657
Drugs	57,987	58,176	17,291	16,773	9,016	11,568	10,007	8,102	4,393	4,413	7,187	7,055	10,093	10,265
Integrated circuits	8,080	12,766	3,499	3,433	1,460	6,068	1,324	1,223	390	549	297	329	1,110	1,164
Telecommunications	28,636	37,783	7,742	8,461	3,278	13,794	6,207	5,651	2,598	2,373	2,071	1,793	6,740	5,711
Internal combustion engines	16,887	18,762	4,363	3,942	2,287	3,416	4,305	5,434	1,884	1,498	1,581	1,451	2,467	3,021
Steel and iron	18,745	18,529	3,077	2,653	5,531	7,323	2,438	1,842	944	688	756	460	5,999	5,563
	National shares													
All technologies			0.27	0.23	0.15	0.20	0.20	0.17	0.07	0.06	0.07	0.06	0.25	0.28
Robotics			0.28	0.14	0.09	0.13	0.15	0.14	0.10	0.07	0.03	0.04	0.35	0.49
Lasers			0.47	0.30	0.11	0.37	0.13	0.10	0.10	0.06	0.05	0.05	0.14	0.12
Microbiology-enzymology			0.21	0.26	0.47	0.34	0.13	0.12	0.03	0.04	0.08	0.06	0.09	0.17
Drugs			0.30	0.29	0.16	0.20	0.17	0.14	0.08	0.08	0.12	0.12	0.17	0.18
Integrated circuits			0.43	0.27	0.18	0.48	0.16	0.10	0.05	0.04	0.04	0.03	0.14	0.09
Telecommunications			0.27	0.22	0.11	0.37	0.22	0.15	0.09	0.06	0.07	0.05	0.24	0.15
Internal combustion engines			0.26	0.21	0.14	0.18	0.25	0.29	0.11	0.08	0.09	0.08	0.15	0.16
Steel and iron			0.16	0.14	0.30	0.40	0.13	0.10	0.05	0.04	0.04	0.02	0.32	0.30
	Index: 1 = no emphasis or de-emphasis													
All technologies			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Robotics			0.04	-0.41	-0.38	-0.35	-0.24	-0.20	0.47	0.11	-0.55	-0.37	0.40	0.78
Lasers			0.76	0.32	-0.25	0.81	-0.36	-0.43	0.48	0.06	-0.32	-0.22	0.43	-0.56
Microbiology-enzymology			-0.23	0.12	2.17	0.68	-0.34	-0.28	-0.61	-0.26	0.18	00	-0.65	-0.37
Drugs			0.11	0.26	0.06	-0.02	-0.13	-0.19	0.12	0.28	0.77	0.93	-0.30	-0.36
Integrated circuits			0.62	0.17	0.23	1.35	-0.17	-0.44	-0.29	-0.27	-0.47	-0.59	-0.45	-0.67
Telecommunications			0.01	-0.02	-0.22	0.80	0.10	-0.13	0.34	0.06	0.03	-0.24	-0.06	-0.05
Internal combustion engines			-0.03	-0.08	-0.08	-0.10	0.29	0.69	0.64	0.35	0.34	0.23	-0.42	-0.41
Steel and iron			-0.39	-0.38	1.01	0.95	-0.34	-0.42	-0.26	-0.37	-0.42	-0.60	0.28	0.09

SOURCE: U.S. Patent and Trademark Office, Office of Technology Assessment and Forecast, unpublished data.

See table 1-4 in text.

Science Indicators—1985

Appendix table 1-21. National expenditures on research by sector and field of science, for selected countries: 1981

Country, sector, and activity	Natural Sciences	Engineering	Medical sciences	Agricultural sciences	Social sciences	Unclassified
	Million dollars					
United States	$5,181	$2,018	$1,705	$772	$522	$4,503
Government:						
Basic research	NA	NA	NA	NA	NA	1,302
Applied research	NA	NA	NA	NA	NA	2,732
Industry:						
Basic research	579	402	97	NA	NA	285
Colleges and universities:						
Research and development	2,842	960	1,599	772	501	145
University-affiliated FFRDC's:						
Research and development	1,760	656	8	1	21	39
West Germany	2,193	879	943	243	764	533
Government:						
Research and development	1,338	343	222	138	228	NA
Industry basic research:						
Basic research	NA	NA	NA	NA	NA	533
Colleges and universities:						
Research and development	829	504	718	103	515	NA
Private non-profit institutions:						
Research and development	25	32	3	2	21	NA
Japan	674	2,225	1,717	354	2,680	2,108
Government:						
Basic research	NA	NA	NA	NA	NA	384
Applied research	NA	NA	NA	NA	NA	868
Industry:						
Basic research	NA	NA	NA	NA	NA	856
Colleges and universities:						
Basic and applied research	595	1,444	1,639	327	2,534	NA
Private non-profit institutions:						
Basic and applied research	79	781	78	27	145	NA

Note: NA = Not available.

Note: Currency conversions based on purchasing power parities.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources 1984* (NSF 84-311); National Science Foundation, *Research and Development in Industry,1981* (NSF 83-325); National Science Foundation, *Academic Science/Engineering: R&D Funds Fiscal Year 1982* (NSF 84-308); Organisation for Economic Co-operation and Development, *International Statistical Year 1981*.

Science Indicators—1985

Appendix table 1-22. Non-immigrant foreign students in U.S. colleges and universities, by country of citizenship: 1972/73-1983/84

Country	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83	1983/84
	Students											
Total	146,097	151,066	154,580	179,344	203,068	235,509	263,938	286,343	311,882	326,299	336,985	338,894
United Kingdom	3,624	3,375	2,770	2,760	3,580	4,050	4,300	4,280	4,440	5,540	5,880	5,860
France	1,849	1,736	1,610	1,600	1,780	2,130	2,350	2,250	2,570	2,990	3,170	3,180
West Germany	1,927	1,858	1,610	1,630	2,040	2,510	2,980	3,000	3,310	3,640	3,730	3,790
U.S.S.R	59	45	NA	NA	210	160	170	600	630	430	360	260
Poland	402	371	260	260	260	280	370	390	450	540	710	730
Other East Europe	985	871	640	730	930	530	630	590	590	600	930	820
Japan	4,653	4,745	5,930	7,070	7,160	9,050	10,490	12,260	13,500	14,020	13,610	13,010
Taiwan	9,633	8,416	10,250	11,330	12,100	13,650	15,460	17,560	19,460	20,520	20,770	21,960
Iran	7,838	9,623	13,780	19,900	23,310	36,220	45,340	51,310	47,550	35,860	26,760	20,360
China	NA	NA	NA	120	320	NA	NA	1,000	2,770	4,350	6,230	8,140
Canada	9,679	8,747	8,430	9,540	11,120	12,600	15,120	15,130	14,320	14,950	14,020	15,150
Other countries	105,448	111,279	109,300	124,404	140,258	154,329	166,728	177,973	202,292	222,859	240,815	245,634

Note: NA = Not available.

SOURCE: Institute of International Education, *Open Doors* (annual: 1972-1984).

See figure 1-16.

Appendix table 1-23. Doctoral degrees[1] awarded to foreign students as a percent of all doctoral degrees from U.S. universities, by field: 1960-84[2]

Field	1960	1965	1970	1975	1980	1981	1982	1983	1984
	Percent								
All fields	12.2	14.4	14.3	16.2	16.4	17.2	18.2	19.2	20.1
Science and engineering	15.4	18.0	18.4	22.2	21.4	22.1	23.0	24.3	25.5
Physical sciences	12.4	15.3	16.8	22.7	22.2	22.1	22.6	23.8	24.2
Physics and astronomy	12.4	16.6	17.6	27.6	25.1	26.2	28.2	30.2	29.0
Chemistry	11.1	13.6	15.4	19.7	22.4	21.2	21.4	20.6	22.2
Earth sciences[3]	17.9	18.0	20.6	21.3	17.2	17.0	17.2	22.0	21.7
Mathematical sciences	19.1	14.2	15.9	24.3	27.5	30.8	33.6	37.5	39.0
Mathematics	NA	NA	NA	NA	27.9	32.2	33.7	38.3	39.7
Computer sciences	NA	NA	NA	NA	26.4	26.3	33.2	35.5	37.5
Engineering	23.2	22.5	26.4	41.8	47.8	51.5	53.1	56.1	55.4
Life sciences	17.9	22.5	18.8	19.6	16.8	16.6	15.8	16.8	17.4
Biological sciences	15.2	19.2	15.9	14.8	12.0	11.1	12.2	12.0	12.6
Agriculture and forestry	25.9	33.7	30.7	37.4	36.7	37.7	30.4	34.6	35.7
Social sciences	11.8	13.7	14.3	13.6	12.7	13.0	14.0	13.8	15.7
Psychology	5.3	4.3	5.3	5.8	4.1	3.9	3.7	4.5	4.5
Other social sciences	17.4	20.4	20.8	20.0	21.6	24.0	26.0	25.4	29.3
Nonscience	6.4	7.8	7.9	8.8	10.1	11.0	12.0	12.2	12.8

[1] Percent of those whose doctorate is known.

[2] Fiscal year of doctorate.

[3] Includes oceanography.

Note: NA = Not available.

SOURCE: National Science Foundation, *Science and Engineering Doctorates: 1960-82* (NSF 83-328), and unpublished statistics.

See figure 1-17.

Science Indicators—1985

Appendix table 1-24. Foreign PhDs[1] with postdoctoral plans, by field of science: 1972 and 1983

	Total non-resident	Total with firm plans	Firm plans in U.S.	Postdoctoral study[2]	Academic employment	Industrial employment	Other U.S. employment	Firm plans abroad
				Doctoral recipients—1972				
All S/E fields	2,169	1,397	408	251	94	30	30	**989**
Physical sciences	387	240	105	94	6	4	0	**135**
Physics/astronomy	209	132	64	56	4	3	0	**68**
Chemistry	178	108	41	38	2	1	0	**67**
Earth, env. & marine sci.	64	43	10	4	3	1	2	**33**
Engineering	519	291	93	55	14	20	4	**198**
Mathematical sciences	169	102	42	16	22	2	2	**60**
Computer science	NA	NA	NA	NA	NA	NA	NA	**NA**
Life sciences	537	359	83	71	7	2	1	**276**
Biological sciences	305	205	70	61	5	1	1	**135**
Agricultural sciences	232	154	13	10	2	1	0	**141**
Social sciences	415	314	62	9	33	0	20	**252**
Psychology	78	48	13	2	9	1	1	**35**
				Doctoral recipcients—1983				
All S/E fields	3,327	1,992	938	434	291	190	21	**1,054**
Physical sciences	539	333	212	164	19	27	2	**121**
Physics/astronomy	256	164	96	75	9	11	1	**68**
Chemistry	283	169	116	89	10	16	1	**53**
Earth, env. & marine sci.	106	66	22	16	4	0	2	**44**
Engineering	1,169	694	391	99	141	141	8	**303**
Mathematical sciences	209	124	74	31	39	3	1	**50**
Computer science	72	47	32	3	18	11	0	**15**
Life sciences	629	376	114	95	12	4	3	**262**
Biological sciences	322	190	100	86	7	4	3	**90**
Agricultural sciences	307	186	14	9	5	0	0	**172**
Social sciences	524	312	74	14	53	3	4	**238**
Psychology	79	40	19	12	5	1	1	**21**
				Percent of all foreign recipients with firm plans—1972				
All S/E fields		100	29.2	18.0	6.7	2.1	2.1	70.8
Physical sciences		100	43.8	39.2	2.5	1.7	0.0	56.3
Physics/astronomy		100	48.5	42.4	3.0	2.3	0.0	51.5
Chemistry		100	38.0	35.2	1.9	0.9	0.0	62.0
Earth, env. & marine sci.		100	23.3	9.3	7.0	2.3	4.7	76.7
Engineering		100	32.0	18.9	4.8	6.9	1.4	68.0
Mathematical sciences		100	41.2	15.7	21.6	2.0	2.0	58.8
Computer science		NA	NA	NA	NA	NA	NA	NA
Life sciences		100	23.1	19.8	1.9	0.6	0.3	76.9
Biological sciences		100	34.1	29.8	2.4	0.5	0.5	65.9
Agricultural sciences		100	8.4	6.5	1.3	0.6	0.0	91.6
Social sciences		100	19.7	2.9	10.5	0.0	6.4	80.3
Psychology		100	27.1	4.2	18.8	2.1	2.1	72.9
				Percent of all foreign recipients with firm plans—1983				
All S/E fields		100	47.1	21.8	14.6	9.5	1.1	52.9
Physical sciences		100	63.7	49.2	5.7	8.1	0.6	36.3
Physics/astronomy		100	58.5	45.7	5.5	6.7	0.6	41.5
Chemistry		100	68.6	52.7	5.9	9.5	0.6	31.4
Earth, env. & marine sci.		100	33.3	24.2	6.1	0.0	3.0	66.7
Engineering		100	56.3	14.3	20.3	20.3	1.2	43.7
Mathematical sciences		100	59.7	25.0	31.5	2.4	0.8	40.3
Computer science		100	68.1	6.4	38.3	23.4	0.0	31.9
Life sciences		100	30.3	25.3	3.2	1.1	0.8	69.7
Biological sciences		100	52.6	45.3	3.7	2.1	1.6	47.4
Agricultural sciences		100	7.5	4.8	2.7	0.0	0.0	92.5
Social sciences		100	23.7	4.5	17.0	1.0	1.3	76.3
Psychology		100	47.5	30.0	12.5	2.5	2.5	52.5

[1] Excludes foreign Ph.D.s holding permanent residence visas for the United States.

[2] Includes postdoctoral research assistants.

Note: NA = not available.

SOURCE: National Research Council, Office of Scientific and Engineering Personnel, Doctorate Records File, unpublished statistics.

See figure 1-18.

Appendix table 1-25. U.S. doctoral recipients[1] studying abroad[2], by field: 1967-83

Year	All S/E fields	Physics	Chemistry	Earth, env., & marine science	Engineering	Biosciences	Mathematics[4]	Agricultural sciences	Social sciences	Psychology
Percent of doctoral recipients studying abroad										
1967	2.13	3.49	4.33	1.73	1.11	3.70	1.39	0.71	0.20	0.73
1968	1.73	2.72	3.07	1.36	1.05	3.41	0.71	0.63	0.18	0.43
1969	1.86	3.97	3.19	2.87	0.91	3.39	0.32	0.97	0.33	0.54
1970	1.90	4.18	3.43	2.77	0.75	3.23	1.12	1.00	0.27	0.66
1971	2.39	5.59	5.72	3.16	1.56	3.22	0.74	0.90	0.16	0.64
1972	2.10	4.70	5.14	0.94	1.15	3.42	1.37	1.46	0.18	0.46
1973	1.44	3.42	2.27	1.81	0.63	2.70	1.45	1.13	0.29	0.30
1974	1.53	3.89	3.37	0.79	0.53	2.71	0.53	0.95	0.23	0.50
1975	1.54	2.80	3.03	0.94	1.02	3.10	1.11	0.79	0.36	0.46
1976	1.65	3.14	3.42	1.11	0.91	4.26	0.68	0.75	0.59	0.33
1977	1.43	3.16	2.23	2.75	0.82	3.62	0.58	0.78	0.43	0.25
1978	1.26	2.65	2.32	2.41	0.85	2.55	0.25	0.35	0.16	0.35
1979	1.61	2.99	2.10	1.77	1.15	3.37	1.21	1.05	0.48	0.31
1980	1.42	2.87	2.21	1.30	0.79	2.94	1.02	1.49	0.26	0.28
1981	1.73	4.91	2.41	2.25	0.98	3.51	0.79	1.27	0.37	0.25
1982	1.63	2.30	3.01	2.16	0.70	3.09	0.87	2.24	0.59	0.21
1983	1.46	3.43	2.74	1.95	1.08	2.31	0.66	1.55	0.52	0.26
Doctoral recipients studying abroad										
1967	236	39	67	6	24	75	10	3	3	9
1968	214	34	49	5	25	83	6	3	3	6
1969	258	50	56	12	25	92	3	5	6	9
1970	296	60	70	12	22	96	12	6	6	12
1971	397	84	115	16	46	105	8	6	4	13
1972	347	66	93	5	34	110	15	9	5	10
1973	234	45	37	10	17	88	15	7	8	7
1974	212	41	52	4	12	80	5	5	6	7
1975	235	29	46	5	21	96	11	5	10	12
1976	229	31	48	6	17	92	6	4	16	9
1977	191	29	30	16	14	75	5	4	11	7
1978	177	23	30	13	13	80	2	2	4	10
1979	228	26	28	10	18	110	10	6	11	9
1980	201	22	28	7	12	101	8	9	6	8
1981	245	38	32	11	14	120	6	8	8	8
1982	225	17	41	12	10	106	6	15	12	6
1983	214	26	39	10	16	89	3	12	11	8
All U.S. doctoral recipients										
1967	11,063	1,119	1,548	347	2,155	2,026	719	421	1,488	1,240
1968	12,397	1,249	1,594	367	2,378	2,436	841	479	1,647	1,406
1969	13,846	1,258	1,753	418	2,736	2,712	937	516	1,845	1,671
1970	15,545	1,436	2,038	433	2,944	2,975	1,076	602	2,225	1,816
1971	16,588	1,503	2,011	506	2,948	3,263	1,074	663	2,578	2,042
1972	16,532	1,403	1,808	531	2,952	3,216	1,095	618	2,739	2,170
1973	16,246	1,314	1,633	554	2,699	3,258	1,033	617	2,803	2,335
1974	13,840	1,054	1,542	504	2,267	2,957	947	526	2,652	1,391
1975	15,261	1,034	1,519	530	2,065	3,100	992	633	2,781	2,607
1976	13,851	987	1,405	540	1,869	2,160	881	536	2,705	2,768
1977	13,387	919	1,343	581	1,705	2,071	862	514	2,571	2,821
1978	14,056	868	1,293	540	1,533	3,134	809	573	2,448	2,858
1979	14,184	870	1,335	566	1,567	3,262	826	573	2,290	2,895
1980	14,112	766	1,269	538	1,517	3,430	788	605	2,290	2,909
1981	14,175	774	1,329	488	1,425	3,421	759	629	2,191	3,159
1982	13,825	740	1,362	556	1,429	3,427	686	670	2,041	2,914
1983	14,667	759	1,424	512	1,481	3,846	457	773	2,125	3,085

[1] Includes U.S. citizens and foreign citizens with permanent resident status.

[2] Includes all U.S. residents reporting firm committments for post-doctoral work abroad.

[3] Includes medical sciences.

[4] Includes computer science.

SOURCE: National Research Council, Office of Scientific and Engineering Personnel, Doctorate Records File unpublished data; National Science Foundation, *Science and Engineering Doctorates: 1960-82* (NSF 83-328), National Research Council, *Summary Report 1983: Doctorate Recipients from United States Universities*, National Academy Press, Washington, D.C., 1983.

See figure 1-19.

Appendix table 1-26. U.S. academic exchange visas issued, by nationality of recipient: 1978-84

Country	1978	1979	1980	1981	1982	1983	1984
	Visas						
Total	67,579	72,131	77,557	84,106	85,714	91,164	97,646
United Kingdom	7,219	8,774	9,394	8,416	8,362	8,411	8,836
France	3,274	3,194	3,854	4,073	3,962	4,395	4,975
West Germany	3,572	3,996	4,420	4,649	5,208	5,823	7,415
U.S.S.R	176	275	234	180	183	160	98
Poland	905	1,008	1,184	1,374	1,122	863	990
Other East Europe	1,032	974	1,254	1,239	1,211	1,400	1,659
Japan	5,060	6,110	6,190	6,983	6,568	7,403	7,571
Taiwan	617	564	819	1,061	1,119	1,309	1,306
Iran	876	266	32	49	87	99	176
Other countries	44,828	46,970	50,176	56,082	57,892	61,301	64,620

SOURCE: Immigrant and Visa Control and Reporting Division, U.S. Department of State, unpublished data.

See figure 1-21.

Appendix table 1-27. Distribution of scientific and technical articles[1] in U.S. and foreign journals, by field[2]: 1973-82

Field[2]	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
	U.S. articles[3] in foreign journals[4]									
All fields	19,157	19,176	18,913	19,463	19,373	20,365	20,080	20,644	30,559	31,711
Clinical medicine	4,695	4,850	5,000	4,854	4,975	5,384	5,268	5,118	8,712	8,960
Biomedicine	4,124	4,092	4,098	4,544	4,306	4,720	4,896	4,817	6,365	6,450
Biology	1,660	1,711	1,999	2,180	2,049	2,006	2,037	2,026	3,316	3,622
Chemistry	2,346	2,342	2,107	1,970	2,018	2,168	2,036	2,321	2,998	3,052
Physics	2,661	2,702	2,513	2,516	2,742	2,535	2,525	2,853	3,761	3,946
Earth and space sciences	1,200	1,131	996	1,109	1,126	1,152	1,179	1,176	1,810	1,674
Engineering and technology	1,382	1,338	1,195	1,255	1,302	1,565	1,351	1,557	2,444	2,785
Mathematics	1,089	1,010	1,005	1,035	855	835	768	771	1,150	1,220
	Foreign articles in U.S. journals									
All fields	28,425	28,902	30,425	32,502	33,058	33,860	36,353	36,161	50,393	51,709
Clinical medicine	6,794	6,867	6,882	7,560	7,923	8,398	8,898	9,283	13,451	14,790
Biomedicine	4,148	4,340	5,144	5,154	5,377	5,158	5,493	5,584	7,414	8,051
Biology	2,013	1,889	1,865	1,803	1,971	2,296	2,587	2,417	3,399	3,580
Chemistry	5,484	5,700	6,270	7,062	6,583	6,252	6,769	6,703	8,808	8,785
Physics	4,118	4,384	4,434	5,048	5,143	5,556	6,095	6,144	7,461	7,794
Earth and space sciences	1,284	1,204	1,108	1,170	1,146	1,283	1,251	1,280	2,051	1,978
Engineering and technology	3,723	3,611	3,748	3,618	3,848	3,904	4,241	3,792	5,946	4,960
Mathematics	861	907	974	1,087	1,067	1,013	1,019	958	1,861	1,770
	Balance[5]									
All fields	9,268	9,726	11,512	13,039	13,685	13,495	16,273	15,517	19,834	19,998
Clinical medicine	2,099	2,017	1,882	2,706	2,948	3,014	3,630	4,165	4,739	5,830
Biomedicine	24	248	1,046	610	1,071	438	597	767	1,049	1,601
Biology	353	178	-134	-377	-78	290	550	391	83	-42
Chemistry	3,138	3,358	4,163	5,092	4,565	4,084	4,733	4,382	5,810	5,733
Physics	1,457	1,682	1,921	2,532	2,401	3,021	3,570	3,291	3,700	3,848
Earth and space sciences	84	73	112	61	20	131	72	104	241	304
Engineering and technology	2,341	2,273	2,553	2,363	2,546	2,339	2,890	2,235	3,502	2,175
Mathematics	-228	-103	-31	52	212	178	251	187	711	550

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[1] Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. The last years use over 3,500 journals on the 1981 Science Citation Index Corporate Tapes.

[2] See appendix table 1-8 for a description of the subfields included in these fields.

[3] When an article is written by researchers from more than one country, that article is prorated across the countries involved. For example, if a given article has several authors from France and the United States, it is split to these countries on the basis of the number of organizations represented by these authors.

[4] The country of a journal is determined by where it is published.

[5] When the balance is negative, more U.S. articles are being published in journals abroad than foreign articles in U.S. journals. When the balance is positive, the United States is publishing more foreign articles than U.S. researchers are publishing abroad.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 1-22.

Appendix table 1-28. Total references[1] in U.S. articles and references to U.S. articles to articles from other countries, by field: 1973-82

Field[2]	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
	Percentage of references in U.S. articles to articles from other countries									
All fields	40.9	41.6	42.6	42.4	42.6	38.0	43.9	44.3	44.8	45.9
Clinical medicine	35.8	37.4	38.0	37.6	37.6	37.4	38.4	38.6	39.8	41.2
Biomedicine	41.7	42.8	43.4	43.0	43.1	45.0	44.7	42.5	43.7	44.9
Biology	37.1	38.2	40.5	39.7	41.2	41.2	41.1	42.8	43.5	44.3
Chemistry	54.9	54.8	55.3	56.6	57.3	58.4	58.6	59.9	61.4	61.3
Physics	47.9	47.2	48.4	49.8	51.0	52.0	54.2	54.5	55.4	57.2
Earth and space sciences	35.6	36.4	38.9	37.6	37.0	37.2	36.6	38.6	38.9	38.9
Engineering and technology	39.8	38.0	42.4	40.3	41.8	41.8	44.4	43.5	44.6	44.4
Mathematics	40.0	41.6	43.4	45.2	45.8	44.4	44.0	46.8	49.9	49.3
	References in U.S. articles to articles from other countries									
All fields	591,737	613,585	632,320	659,361	652,553	650,665	674,285	694,927	993,749	1,078,463
Clinical medicine	157,408	171,209	174,199	188,659	192,408	203,269	208,923	218,918	340,808	371,473
Biomedicine	151,450	159,638	164,667	170,456	166,551	148,406	157,504	163,834	230,700	252,812
Biology	34,110	35,756	38,031	39,001	39,623	41,132	44,293	44,648	72,824	79,162
Chemistry	97,410	96,318	95,759	101,930	94,567	101,890	97,045	103,500	127,325	135,476
Physics	84,969	84,056	86,734	87,911	90,354	88,404	94,787	98,668	120,444	134,179
Earth and space sciences	25,303	27,880	30,714	30,172	28,971	30,042	34,544	32,357	50,805	53,455
Engineering and technology	21,243	20,215	21,738	21,026	20,566	21,279	22,574	23,864	35,283	36,718
Mathematics	10,022	9,796	10,157	10,644	10,037	9,723	9,312	9,138	15,561	15,187
	Total references in U.S. articles									
All fields	1,447,639	1,476,731	1,483,931	1,556,006	1,532,339	1,499,100	1,535,000	1,567,912	2,217,026	2,349,033
Clinical medicine	440,065	457,582	458,150	501,407	511,206	543,431	543,566	566,426	856,352	901,026
Biomedicine	363,439	373,233	379,741	396,005	386,276	329,452	352,096	385,065	527,722	562,783
Biology	91,948	93,539	93,931	98,211	96,113	99,871	107,698	104,421	167,388	178,759
Chemistry	177,420	175,716	173,261	180,081	165,107	174,515	165,474	172,659	207,313	221,119
Physics	177,504	178,064	179,183	176,606	177,121	169,999	174,945	181,197	217,396	234,437
Earth and space sciences	71,159	76,588	78,880	80,303	78,222	80,762	94,403	83,800	130,498	137,464
Engineering and technology	53,346	53,164	51,284	52,231	49,191	50,948	50,839	54,799	79,189	82,628
Mathematics	25,059	23,531	23,389	23,537	21,914	21,904	21,143	19,545	31,167	30,816

[1] Obtained by dividing the number of references found in articles written by scientists and engineers at U.S. institutions which were to articles written by S/E's at foreign institutions by the total number of references in U.S. authored articles. References were sought in the articles published in over 2,100 influential journals carried on the Corporate Tapes of the 1973 *Science Citations Index* of the Institute of Scientific Information. The last two years use articles in over 3,500 journals in the 1981 *Science Citation Index*.

[2] See appendix table 1-8 for subfields included in the fields.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 1-20.

Appendix table 1-29. Internationally co-authored articles and all institutional co-authored articles, by field: 1973-82

Field and subfield[1]	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
	Internationally co-authored articles as a percent of all institutionally co-authored articles[2]									
All fields	12.7	13.3	14.0	14.8	15.1	15.4	16.1	16.3	17.3	17.2
Clinical medicine	6.6	6.9	6.8	7.8	7.5	7.7	8.1	8.1	8.8	9.1
Biomedicine	13.7	14.2	15.2	15.7	16.3	16.4	16.9	17.1	17.9	18.2
Biology	15.5	13.6	15.4	17.0	17.0	17.9	18.6	18.3	19.9	17.7
Chemistry	16.3	17.2	17.7	18.1	20.7	20.0	21.5	21.8	22.6	22.6
Physics	22.7	23.7	25.4	25.9	27.5	29.4	27.8	30.2	32.6	33.0
Earth and space sciences	23.1	22.5	24.6	27.7	27.5	28.7	28.7	30.7	30.2	30.5
Engineering and technology	13.2	14.0	15.5	14.0	16.2	17.2	18.2	18.2	19.7	19.9
Mathematics	34.3	39.5	39.8	38.6	37.9	38.8	40.0	42.5	42.0	43.9
	Internationally co-authored articles									
All fields	8,420	9,113	9,737	10,559	11,338	12,317	13,225	14,057	16,558	21,745
Clinical medicine	1,881	2,013	1,989	2,314	2,440	2,709	2,837	3,032	3,634	5,084
Biomedicine	1,454	1,581	1,775	1,862	2,032	2,156	2,395	2,533	2,828	3,765
Biology	723	655	779	853	915	1,007	1,116	1,051	1,371	1,804
Chemistry	1,088	1,241	1,286	1,384	1,546	1,600	1,763	1,932	2,253	2,802
Physics	1,570	1,757	1,933	2,142	2,320	2,548	2,758	2,960	3,470	4,217
Earth and space sciences	647	658	698	830	849	956	1,021	1,108	1,251	1,709
Engineering and technology	584	650	720	626	721	806	803	842	1,096	1,416
Mathematics	473	558	557	548	515	535	532	600	656	948
	All institutionally co-authored articles									
All fields	66,105	68,529	69,579	71,220	75,283	79,955	81,894	86,115	95,858	126,509
Clinical medicine	28,617	28,974	29,078	29,564	32,643	35,160	35,097	37,250	41,239	55,652
Biomedicine	10,648	11,117	11,683	11,845	12,436	13,116	14,144	14,807	15,839	20,642
Biology	4,660	4,829	5,073	5,024	5,405	5,620	5,985	5,744	6,875	10,188
Chemistry	6,694	7,224	7,264	7,632	7,485	7,996	8,185	8,856	9,986	12,393
Physics	6,897	7,410	7,601	8,271	8,433	8,661	9,179	9,792	10,651	12,772
Earth and space sciences	2,798	2,920	2,832	2,994	3,085	3,335	3,553	3,615	4,146	5,595
Engineering and technology	4,412	4,642	4,647	4,470	4,437	4,689	4,421	4,638	5,562	7,108
Mathematics	1,379	1,413	1,401	1,420	1,359	1,378	1,330	1,413	1,561	2,160

[1] See appendix table 1-8 for the subfields included in these fields.

[2] Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. The last two years use over 3,500 journals on the 1981 *Science Citation Index* Corporate Tapes.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 1-23.

Appendix table 1-30. Internationally co-authored articles and all institutionally co-authored articles, for selected countries: 1973-82

Country	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
					Internationally co-authored articles as a percent of all institutionally co-authored articles[1]					
West Germany	35.6	37.3	38.2	40.6	41.3	41.6	43.8	46.2	45.4	**46.9**
United Kingdom	35.3	37.0	37.7	39.6	40.7	40.2	40.4	41.8	41.8	**41.6**
Canada	37.0	38.0	37.3	38.5	38.4	39.4	39.9	40.0	42.7	**42.7**
France	26.7	26.9	29.8	31.4	32.5	33.5	33.9	34.0	34.9	**37.3**
U.S.S.R.	9.6	10.9	13.3	14.2	17.3	16.3	20.1	19.9	18.3	**18.5**
United States	14.0	14.3	15.0	15.9	15.9	15.7	16.6	16.9	17.6	**18.2**
Japan	16.4	16.4	16.1	15.2	15.9	15.5	16.3	16.4	17.3	**18.2**
					Internationally co-authored articles					
West Germany	1,283	1,527	1,568	1,741	1,923	2,176	2,244	2,459	3,557	**3,767**
United Kingdom	2,029	2,219	2,364	2,574	2,633	2,784	2,889	3,159	4,492	**4,626**
Canada	1,302	1,369	1,422	1,532	1,599	1,715	1,812	1,819	2,718	**562**
France	1,131	1,209	1,460	1,591	1,769	1,837	2,003	2,153	3,062	**3,342**
U.S.S.R.	288	318	380	432	523	528	604	637	836	**900**
United States	4,807	5,037	5,254	5,675	5,972	6,248	6,755	7,192	10,268	**11,013**
Japan	472	495	543	555	635	678	767	872	1,334	**1,516**
					All institutionally co-authored articles					
West Germany	3,605	4,093	4,108	4,287	4,654	5,228	5,128	5,324	7,842	**8,037**
United Kingdom	5,749	6,002	6,268	6,501	6,473	6,925	7,159	7,553	10,747	**11,131**
Canada	3,521	3,004	3,809	3,976	4,166	4,358	4,543	4,542	6,368	**6,697**
France	4,233	4,492	4,901	5,065	5,445	5,491	5,902	6,341	8,779	**8,967**
U.S.S.R.	3,011	2,926	2,860	3,033	3,031	3,233	3,005	3,199	4,578	**4,876**
United States	34,364	35,338	35,100	35,799	37,618	39,768	40,784	42,508	58,472	**60,649**
Japan	2,881	3,018	3,363	3,657	3,984	4,386	4,696	5,308	7,699	**8,336**

[1] Based on the articles, notes, and reviews in over 2,100 of the influential journals carried on the 1973 *Science Citation Index* Corporate Tapes of the Institute for Scientific Information. The last two years use over 3,500 journals on the 1981 *Science Citation Index* Corporate Tapes

SOURCE: Computer Horizons, Inc., unpublished data

See figure 1-24

Appendix table 2-1. Gross national product price deflators used in the calculation of 1972 constant dollars throughout this report: 1960-85

Year	Calendar year GNP price deflator	Fiscal year GNP price deflator
1960	0.6870	0.6957
1961	.6933	.7036
1962	.7061	.7137
1963	.7167	.7256
1964	.7277	.7338
1965	.7436	.7498
1966	.7676	.7696
1967	.7906	.7944
1968	.8254	.8231
1969	.8679	.8617
1970	.9145	.9104
1971	.9601	.9562
1972	1.0000	1.0000
1973	1.0575	1.0445
1974	1.1508	1.1206
1975	1.2579	1.2326
1976	1.3234	1.3188
1977	1.4005	1.4076
1978	1.5042	1.5033
1979	1.6342	1.6346
1980	1.7842	1.7762
1981	1.9560	1.9534
1982	2.0738	2.0933
1983	2.1534	2.1762
1984	2.2344	2.2591
1985	2.3198	2.3428

Note: Calendar year deflators were taken directly from sources cited below. Fiscal year deflators were calculated from quarterly data in the same sources.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business* and *Commerce News*, and Executive Office of the President, Office of Management and Budget, estimates.

See figure 2-3.

Science Indicators—1985

Appendix table 2-2. National expenditures for R&D, by source as a percent of gross national product (GNP): 1960-85

	Current dollars				Constant 1972 dollars[1]				As a percent of GNP		
Year	GNP	Total	Federal	Other	GNP	Total	Federal	Other	Total	Total	Other
	Billion dollars								Percent		
1960	$506.5	$13.5	$8.7	$4.8	$737.3	$19.6	$12.7	$6.9	2.67	1.72	0.95
1961	524.6	14.3	9.3	5.0	756.7	20.6	13.3	7.3	2.73	1.77	0.95
1962	565.0	15.4	9.9	5.5	800.2	21.7	14.0	7.7	2.73	1.75	0.97
1963	596.7	17.1	11.2	5.9	832.6	23.7	15.6	8.1	2.87	1.88	0.99
1964	637.7	18.9	12.5	6.4	876.3	25.9	17.2	8.7	2.96	1.96	1.00
1965	691.1	20.0	13.0	7.0	929.4	26.9	17.4	9.5	2.89	1.88	1.01
1966	756.0	21.8	14.0	7.8	984.9	28.4	18.2	10.2	2.88	1.85	1.03
1967	799.6	23.1	14.4	8.7	1,011.4	29.2	18.2	11.0	2.89	1.80	1.09
1968	873.4	24.6	14.9	9.7	1,058.2	29.8	18.1	11.7	2.82	1.71	1.11
1969	944.0	25.6	14.9	10.7	1,087.7	29.6	17.2	12.4	2.71	1.58	1.13
1970	992.7	26.1	14.9	11.2	1,085.5	28.6	16.3	12.3	2.63	1.50	1.13
1971	1,077.6	26.7	15.0	11.7	1,122.4	27.8	15.6	12.2	2.48	1.39	1.09
1972	1,185.9	28.5	15.8	12.7	1,185.9	28.5	15.8	12.7	2.40	1.33	1.07
1973	1,326.4	30.7	16.4	14.3	1,254.3	29.1	15.6	13.5	2.31	1.24	1.08
1974	1,434.2	32.9	16.9	16.0	1,246.3	28.8	14.8	14.0	2.29	1.18	1.12
1975	1,549.2	35.2	18.1	17.1	1,231.6	28.2	14.5	13.7	2.27	1.17	1.10
1976	1,718.0	39.0	19.9	19.1	1,298.2	29.5	15.1	14.4	2.27	1.16	1.11
1977	1,918.3	42.8	21.6	21.2	1,369.7	30.5	15.4	15.1	2.23	1.13	1.11
1978	2,163.9	48.1	23.9	24.2	1,438.6	32.0	15.9	16.1	2.22	1.10	1.12
1979	2,417.8	54.9	26.8	28.1	1,479.5	33.6	16.4	17.2	2.27	1.11	1.16
1980	2,631.7	62.6	29.5	33.1	1,475.0	35.1	16.5	18.6	2.38	1.12	1.26
1981	2,957.8	71.8	33.4	38.4	1,512.2	36.7	17.1	19.6	2.43	1.13	1.30
1982	3,069.3	79.3	36.5	42.8	1,480.0	38.2	17.5	20.7	2.58	1.19	1.39
1983 (Prel.)	3,304.8	86.6	40.3	46.3	1,534.7	40.1	18.6	21.5	2.62	1.22	1.40
1984 (Est.)	3,662.8	95.9	44.7	51.2	1,639.3	42.8	19.9	22.9	2.62	1.22	1.40
1985 (Est.)	3,906.3	106.6	49.8	56.8	1,683.9	45.9	21.4	24.5	2.70	1.26	1.44

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

Note: Percents are calculated from unrounded figures. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1984* (NSF 84-311) and unpublished data, and U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business* and *Commerce News*.

See figure 2-1.

Science Indicators—1985

Appendix table 2-3. National expenditures for R&D, by source: 1960-85

Year	Total	Federal Government	Industry	Universities and Colleges[1]	Other Nonprofit institutions
			Million dollars		
1960	$13,523	$8,738	$4,516	$149	$120
1961	14,316	9,250	4,757	165	144
1962	15,394	9,911	5,123	185	175
1963	17,059	11,204	5,456	207	192
1964	18,854	12,537	5,887	235	195
1965	20,044	13,012	6,548	267	217
1966	21,846	13,968	7,328	304	246
1967	23,146	14,395	8,142	345	264
1968	24,605	14,928	9,005	390	282
1969	25,631	14,895	10,010	420	306
1970	26,134	14,892	10,444	461	337
1971	26,676	14,964	10,822	529	361
1972	28,477	15,808	11,710	574	385
1973	30,718	16,399	13,293	613	413
1974	32,864	16,850	14,878	677	459
1975	35,213	18,109	15,820	749	535
1976	39,018	19,914	17,694	810	600
1977	42,783	21,594	19,629	888	672
1978	48,129	23,876	22,450	1,037	766
1979	54,933	26,815	26,081	1,200	837
1980	62,593	29,451	30,911	1,323	908
1981	71,839	33,402	35,941	1,523	973
1982	79,301	36,502	40,088	1,683	1,028
1983 (Prel.)	86,555	40,344	43,246	1,830	1,135
1984 (Est.)	95,925	44,675	47,975	2,080	1,195
1985 (Est.)	106,600	49,775	53,210	2,300	1,315
			Million constant 1972 dollars[2]		
1960	$19,634	$12,674	$6,573	$214	$174
1961	20,585	13,283	6,861	235	206
1962	21,749	13,988	7,255	259	247
1963	23,736	15,572	7,612	285	267
1964	25,855	17,178	8,089	320	267
1965	26,898	17,445	8,805	356	291
1966	28,441	18,180	9,546	395	320
1967	29,240	18,175	10,298	434	333
1968	29,831	18,105	10,910	474	342
1969	29,586	17,210	11,534	487	354
1970	28,613	16,316	11,421	506	369
1971	27,816	15,614	11,272	553	377
1972	28,477	15,808	11,710	574	385
1973	29,147	15,596	12,571	587	393
1974	28,764	14,825	12,931	604	404
1975	28,153	14,537	12,578	608	430
1976	29,511	15,072	13,370	614	454
1977	30,507	15,382	14,015	631	479
1978	32,002	15,878	14,925	690	509
1979	33,612	16,407	15,959	734	512
1980	35,122	16,542	17,325	745	510
1981	36,740	17,087	18,375	780	498
1982	38,155	17,528	19,329	804	493
1983 (Prel.)	40,092	18,646	20,081	841	524
1984 (Est.)	42,824	19,896	21,475	921	532
1985 (Est.)	45,863	21,374	22,942	983	564

[1] Includes state and local government sources.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

Note: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1984* (NSF 84-311) and unpublished data.

See figures 2-2, 2-3, and table 2-1 in text.

Appendix table 2-4. Company funds for R&D, by selected industry: 1980-83

Industries	SIC code	1980	1981	1982	1983
		Million dollars			
Total industries		$30,476	$35,428	$39,512	$42,600
High technology industries:	28	4,264	5,205	6,226	6,839
Chemicals and allied products					
Machinery	35	5,254	6,124	6,977	7,238
Electrical equipment	36	5,431	6,409	7,048	8,570
Aircraft and missiles	372,376	2,570	3,440	3,882	3,441
Professional and scientific instruments	38	2,456	2,978	3,396	3,748
Smokestack manufacturing industries:	33	594	702	721	704
Primary metals					
Fabricated metal products	331-32,3398-99	501	545	510	568
Motor vehicles and equipment	371	4,300	4,219	4,329	4,806
Other transportation equipment	373-75,379	88	80	96	106
Other manufacturing industries	20,22-23,24-25,26, 29,30,32,21,27,31,39	3,981	4,678	5,226	5,563
Nonmanufacturing industries	07-17,41-67,737, 739, 807,891	1,037	1,048	1,101	1,017

SOURCES: National Science Foundation, *Research and Development in Industry, 1982* (NSF 84-325) and unpublished data.

See figure 2-5.

Science Indicators—1985

Appendix table 2-5. National expenditures for R&D, by performer: 1960-85

Year	All Performers	Federal Government	Industry[1]	Universities and colleges[2]	FFRDC's[3]	Other nonprofit institutions[4]
			Million dollars			
1960	$13,523	$1,726	$10,509	$646	$360	$282
1961	14,316	1,874	10,908	763	410	361
1962	15,394	2,098	11,464	904	470	458
1963	17,059	2,279	12,630	1,081	530	539
1964	18,854	2,838	13,512	1,275	629	600
1965	20,044	3,093	14,185	1,474	629	663
1966	21,846	3,220	15,548	1,715	630	733
1967	23,146	3,396	16,385	1,921	673	771
1968	24,605	3,494	17,429	2,149	719	814
1969	25,631	3,503	18,308	2,225	725	870
1970	26,134	4,079	18,067	2,335	737	916
1971	26,676	4,228	18,320	2,500	716	912
1972	28,477	4,590	19,552	2,630	753	952
1973	30,718	4,762	21,249	2,884	817	1,006
1974	32,864	4,911	22,887	3,023	865	1,178
1975	35,213	5,354	24,187	3,409	987	1,276
1976	39,018	5,769	26,997	3,729	1,147	1,376
1977	42,783	6,012	29,825	4,067	1,384	1,495
1978	48,129	6,811	33,304	4,625	1,717	1,672
1979	54,933	7,417	38,226	5,361	1,935	1,994
1980	62,593	7,632	44,505	6,060	2,246	2,150
1981	71,839	8,425	51,810	6,818	2,486	2,300
1982	79,301	9,141	57,995	7,261	2,479	2,425
1983 (Prel.)	86,555	10,582	62,816	7,745	2,737	2,675
1984 (Est.)	95,925	12,300	69,250	8,625	2,775	2,975
1985 (Est.)	106,600	13,300	77,500	9,625	2,975	3,200
			Million constant 1972 dollars[4]			
1960	$19,634	$2,481	$15,297	$929	$517	$410
1961	20,585	2,663	15,733	1,084	583	521
1962	21,749	2,940	16,236	1,267	659	649
1963	23,736	3,141	17,622	1,490	730	752
1964	25,855	3,868	18,569	1,738	857	825
1965	26,898	4,125	19,076	1,966	839	892
1966	28,441	4,184	20,255	2,228	819	955
1967	29,240	4,275	20,725	2,418	847	975
1968	29,831	4,245	21,116	2,611	874	986
1969	29,586	4,065	21,095	2,582	841	1,002
1970	28,613	4,480	19,756	2,565	810	1,002
1971	27,816	4,422	19,081	2,615	749	950
1972	28,477	4,590	19,552	2,630	753	952
1973	29,147	4,559	20,094	2,761	782	951
1974	28,764	4,382	19,888	2,698	772	1,024
1975	28,153	4,344	19,228	2,766	801	1,014
1976	29,511	4,374	20,400	2,828	870	1,040
1977	30,507	4,271	21,296	2,889	983	1,067
1978	32,002	4,531	22,141	3,077	1,142	1,112
1979	33,612	4,538	23,391	3,280	1,184	1,220
1980	35,122	4,297	24,944	3,412	1,264	1,205
1981	36,740	4,313	26,488	3,490	1,273	1,176
1982	38,155	4,367	27,966	3,469	1,184	1,169
1983 (Prel.)	40,092	4,863	29,171	3,559	1,258	1,242
1984 (Est.)	42,824	5,445	31,001	3,818	1,228	1,332
1985 (Est.)	45,863	5,682	33,418	4,112	1,271	1,380

[1] Expenditures for federally funded research and development centers administered by industry and by nonprofit institutions are included in the totals of the respective sectors.

[2] Includes state and local government sources.

[3] Federally funded research and development centers administered by universities.

[4] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1984* (NSF 84-311) and unpublished data.

See figure 2-2.

Appendix table 2-6. National expenditures for R&D, by character of work: 1960-85

Year	Current dollars			Constant 1972 dollars[1]		
	Basic research	Applied research	Development	Basic research	Applied research	Development
	Million dollars					
1960	$ 1,197	$ 3,020	$ 9,306	$1,730	$ 4,380	$13,525
1961	1,401	3,065	9,850	2,003	4,401	14,181
1962	1,724	3,665	10,005	2,426	5,174	14,149
1963	1,965	3,742	11,352	2,721	5,202	15,812
1964	2,289	4,128	12,437	3,128	5,657	17,069
1965	2,555	4,339	13,150	3,417	5,819	17,662
1966	2,814	4,601	14,431	3,659	5,989	18,793
1967	3,056	4,780	15,310	3,852	6,036	19,352
1968	3,296	5,131	16,178	4,001	6,222	19,608
1969	3,441	5,316	16,874	3,986	6,139	19,461
1970	3,549	5,720	16,865	3,894	6,264	18,454
1971	3,672	5,739	17,265	3,836	5,986	17,994
1972	3,829	5,984	18,664	3,829	5,984	18,664
1973	3,946	6,597	20,175	3,766	6,267	19,114
1974	4,239	7,228	21,397	3,757	6,340	18,667
1975	4,608	7,863	22,742	3,720	6,297	18,136
1976	4,977	9,046	24,995	3,771	6,844	18,896
1977	5,537	9,745	27,501	3,939	6,945	19,623
1978	6,392	10,844	30,893	4,251	7,211	20,540
1979	7,257	12,372	35,304	4,440	7,570	21,603
1980	8,079	14,050	40,464	4,543	7,887	22,692
1981	9,180	16,876	45,783	4,698	8,631	23,410
1982	9,931	18,509	50,861	4,757	8,900	24,498
1983 (Prel.)	10,935	20,245	55,375	5,040	9,372	25,680
1984 (Est.)	12,105	21,190	62,630	5,375	9,455	27,994
1985 (Est.)	13,300	22,925	70,375	5,697	9,859	30,308

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars

Note: The National Science Foundation use the following definitions of character of work in its resource surveys

Basic research. Basic research has as its objective "a fuller knowledge or understanding of the subject under study, rather than a practical application thereof." To take into account industrial goals, NSF modifies this definition for the industry sector to indicate that basic research advances scientific knowledge "not having specific commercial objectives, although such investigations may be in fields of present or potential interest to the reporting company."

Applied research. Applied research is directed toward gaining "knowledge or understanding necessary for determining the means by which a recognized and specific need may be met." In industry, applied research includes investigations directed "to the discovery of new scientific knowledge having specific commercial objectives with respect to products or processes."

Development. Development is the "systematic use of the knowledge or understanding gained from research, directed toward the production of useful materials, devices systems or methods, including design and development or prototypes and processes."

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1984* (NSF 84-311) and unpublished data.

See figures 2-2 and 2-7 and table 2-2 in text.

Appendix table 2-7. National expenditures for basic research, by source: 1960-85

Year	Total	Federal government	Industry	Universities and colleges[1]	Other Nonprofit institutions
	Million dollars				
1960	$1,197	$715	$342	$72	$68
1961	1,401	874	361	85	81
1962	1,724	1,131	394	102	97
1963	1,965	1,311	425	121	108
1964	2,289	1,598	433	144	114
1965	2,555	1,809	461	164	121
1966	2,814	1,978	510	197	129
1967	3,056	2,201	492	223	140
1968	3,296	2,336	535	276	149
1969	3,441	2,441	540	298	162
1970	3,549	2,489	528	350	182
1971	3,672	2,529	547	400	196
1972	3,829	2,633	563	415	218
1973	3,946	2,709	605	408	224
1974	4,239	2,912	651	432	244
1975	4,608	3,139	705	478	286
1976	4,977	3,436	769	475	297
1977	5,537	3,823	850	527	337
1978	6,392	4,445	964	605	378
1979	7,257	5,044	1,091	711	411
1980	8,079	5,559	1,265	805	450
1981	9,180	6,209	1,585	909	477
1982	9,931	6,643	1,805	983	500
1983 (Prel.)	10,935	7,262	2,008	1,090	575
1984 (Est.)	12,105	8,055	2,245	1,220	585
1985 (Est.)	13,300	8,855	2,485	1,330	630
	Million constant 1972 dollars[2]				
1960	$1,730	$1,031	$497	$ 103	$98
1961	2,003	1,246	520	121	116
1962	2,426	1,589	558	143	137
1963	2,721	1,812	593	167	150
1964	3,128	2,181	595	196	156
1965	3,417	2,417	620	219	162
1966	3,659	2,571	664	256	168
1967	3,852	2,773	622	281	177
1968	4,001	2,837	648	335	181
1969	3,986	2,930	623	346	187
1970	3,894	2,732	578	384	200
1971	3,836	2,643	570	418	205
1972	3,829	2,633	563	415	218
1973	3,766	2,589	573	391	213
1974	3,757	2,589	567	386	215
1975	3,720	2,540	562	388	230
1976	3,771	2,604	581	360	225
1977	3,939	2,718	607	374	240
1978	4,251	2,957	641	402	251
1979	4,440	3,086	668	435	251
1980	4,543	3,128	709	453	253
1981	4,698	3,178	810	465	244
1982	4,757	3,178	870	470	240
1983 (Prel.)	5,040	3,342	931	501	265
1984 (Est.)	5,375	3,571	1,004	540	260
1985 (Est.)	5,697	3,788	1,070	568	270

[1] Includes state and local government sources.

[2] GNP implicit price deflators used to convert current dollars to constant price dollars.

Note: For a definition of basic research, see appendix table 2-6.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1984* (NSF 84-311) and unpublished data.

See figure 2-11.

Appendix table 2-8. National expenditures for applied research, by source: 1960-85

Year	All sources	Federal government	Industry	Universities and colleges	Other Nonprofit institutions
			Million dollars		
1960	$ 3,020	$1,688	$1,226	$66	$40
1961	3,065	1,754	1,195	69	47
1962	3,665	2,067	1,470	70	58
1963	3,742	2,125	1,483	72	62
1964	4,128	2,397	1,593	77	61
1965	4,339	2,524	1,654	88	73
1966	4,601	2,582	1,841	89	89
1967	4,780	2,694	1,889	102	95
1968	5,131	2,810	2,125	97	99
1969	5,316	2,785	2,320	105	106
1970	5,720	3,080	2,427	98	115
1971	5,739	3,008	2,494	115	122
1972	5,984	3,104	2,615	140	125
1973	6,597	3,394	2,891	172	140
1974	7,228	3,534	3,332	203	159
1975	7,863	3,940	3,517	224	182
1976	9,046	4,534	4,003	283	226
1977	9,745	4,786	4,410	303	246
1978	10,844	5,229	4,981	354	280
1979	12,372	5,870	5,794	404	304
1980	14,050	6,599	6,635	428	328
1981	16,876	7,473	8,529	513	361
1982	18,509	8,135	9,416	580	378
1983 (Prel.)	20,245	9,190	10,045	610	400
1984 (Est.)	21,190	8,805	11,230	720	435
1985 (Est.)	22,925	9,100	12,515	820	490
			Million constant 1972 dollars[2]		
1960	$4,380	$2,442	$1,784	$95	$58
1961	4,401	2,512	1,723	98	68
1962	5,174	2,913	2,082	98	82
1963	5,202	2,948	2,069	99	86
1964	5,657	3,280	2,189	105	84
1965	5,819	3,379	2,224	117	98
1966	5,989	3,359	2,398	116	116
1967	6,036	3,399	2,389	128	120
1968	6,222	3,410	2,575	118	120
1969	6,139	3,222	2,673	122	122
1970	6,264	3,377	2,654	108	126
1971	5,986	3,141	2,598	120	127
1972	5,984	3,104	2,615	140	125
1973	6,267	3,235	2,734	165	133
1974	6,340	3,123	2,896	181	140
1975	6,297	3,173	2,796	182	146
1976	6,844	3,434	3,025	215	171
1977	6,945	3,406	3,149	215	175
1978	7,211	3,478	3,311	235	186
1979	7,570	3,591	3,545	247	186
1980	7,887	3,709	3,753	241	184
1981	8,631	3,824	4,360	263	185
1982	8,900	3,902	4,540	277	181
1983 (Prel.)	9,372	4,243	4,664	280	185
1984 (Est.)	9,455	3,916	5,027	319	194
1985 (Est.)	9,859	3,902	5,396	350	210

[1] Includes state and local government sources.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

Note: For a definition of applied research, see appendix table 2-6.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1984* (NSF 84-311) and unpublished data.

See figure 2-11.

Appendix table 2-9. National expenditures for development, by source: 1960-85

Year	All sources	Federal government	Industry	Universities and colleges[1]	Other nonprofit institutions
	Million dollars				
1960	$9,306	$6,335	$2,948	$11	$12
1961	9,850	6,622	3,201	11	16
1962	10,005	6,713	3,259	13	20
1963	11,352	7,768	3,548	14	22
1964	12,437	8,542	3,861	14	20
1965	13,150	8,679	4,433	15	23
1966	14,431	9,408	4,977	18	28
1967	15,310	9,500	5,761	20	29
1968	16,178	9,782	6,345	17	34
1969	16,874	9,669	7,150	17	38
1970	16,865	9,323	7,489	13	40
1971	17,265	9,427	7,781	14	43
1972	18,664	10,071	8,532	19	42
1973	20,175	10,296	9,797	33	49
1974	21,397	10,404	10,895	42	56
1975	22,742	11,030	11,598	47	67
1976	24,995	11,944	12,922	52	77
1977	27,501	12,985	14,369	59	89
1978	30,893	14,202	16,505	78	108
1979	35,304	15,901	19,196	85	122
1980	40,464	17,293	22,951	90	130
1981	45,783	19,720	25,827	101	135
1982	50,861	21,724	28,867	120	150
1983 (Prel.)	55,375	23,892	31,193	130	160
1984 (Est.)	62,630	27,815	34,500	140	175
1985 (Est.)	70,375	31,820	38,210	150	195
	Million constant 1972 dollars[2]				
1960	$13,525	$9,201	$4,291	$16	$17
1961	14,181	9,526	4,617	16	23
1962	14,149	9,487	4,615	18	28
1963	15,813	10,812	4,950	19	31
1964	17,069	11,717	5,306	19	27
1965	17,662	11,649	5,962	20	31
1966	18,793	12,249	6,484	23	36
1967	19,352	12,003	7,287	25	37
1968	19,608	11,859	7,687	21	41
1969	19,461	11,159	8,238	20	44
1970	18,454	10,207	8,189	14	44
1971	17,994	9,830	8,104	15	45
1972	18,664	10,071	8,532	19	42
1973	19,114	9,772	9,264	32	46
1974	18,667	9,113	9,467	37	49
1975	18,136	8,824	9,220	38	54
1976	18,896	9,034	9,764	39	58
1977	19,623	9,258	10,260	41	63
1978	20,540	9,443	10,973	52	72
1979	21,603	9,729	11,746	52	75
1980	22,692	9,705	12,864	51	73
1981	23,410	10,086	13,204	52	69
1982	24,498	10,449	13,920	57	72
1983 (Prel.)	25,680	11,061	14,485	60	74
1984 (Est.)	27,994	12,409	15,444	62	78
1985 (Est.)	30,308	13,684	16,476	64	84

[1] Includes state and local government sources.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

Note: For a definition of development, see appendix table 2-6.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1984* (NSF 84-311) and unpublished data.

See figure 2-11.

Science Indicators—1985

Appendix table 2-10. Federal outlays for R&D and R&D plant as a percent of total federal outlays and as a percent of controllable federal outlays: 1960-85

Year	Total Federal outlays	Total Federal R&D and R&D plant outlays[1]	Outlays for R&D & R&D plant as a percent of total Federal outlays	Outlays for R&D & R&D plant as a percent of controllable Federal outlays
	Billion dollars		Percent	
1960	$92.2	$7.7	8.4	NA
1961	97.8	9.3	9.5	NA
1962	106.8	10.4	9.7	NA
1963	111.3	12.0	10.8	NA
1964	118.6	14.7	12.4	NA
1965	118.4	14.9	12.6	NA
1966	134.7	16.0	11.9	NA
1967	157.6	16.9	10.7	NA
1968	178.1	17.0	9.5	NA
1969	183.6	16.3	8.9	NA
1970	195.7	15.7	8.0	NA
1971	210.2	16.0	7.6	NA
1972	230.7	16.7	7.2	NA
1973	245.6	17.5	7.1	NA
1974	267.9	18.3	6.8	NA
1975	324.2	19.6	6.0	19.0
1976	364.5	21.0	5.8	18.2
1977	400.5	22.9	5.7	18.2
1978	448.4	25.1	5.6	18.7
1979	491.0	27.0	5.5	18.5
1980	576.7	30.6	5.3	18.7
1981	657.2	34.1	5.2	18.4
1982	728.4	35.8	4.9	19.9
1983	796.0	38.0	4.8	20.8
1984	851.8	41.3	4.8	19.8
1985 (Est.)	959.1	47.5	5.0	18.0
1986 (Est.)	973.7	53.6	5.5	21.6

[1] Reported by Federal agencies.

Note: NA = Not available.

SOURCE: Executive Office of the President, Council of Economic Advisers, *Economic Report of the President, 1983*, p.248; Office of Management and Budget, *Budget of the U.S. Government, Fy 1984*, 1983 p. 9-38 and 9-39; National Science Foundation, *Federal Funds for Research, Development and Other Scientific Activities, Fiscal Years 1983, 1984 and 1985, vol. XXXIII* (NSF 84-336), and earlier volumes.

See figure 2-8.

Appendix table 2-11. Federal funds for R&D, by major budget function: 1960-86

Year	Total	Defense	All other	Defense	All other
	Billion dollars			Percent	
1960	$8	$6	$1	81	19
1961	9	7	2	77	23
1962	10	7	3	70	30
1963	12	8	5	62	38
1964	14	8	6	55	45
1965	15	7	7	50	50
1966	15	8	8	49	51
1967	17	9	8	52	48
1968	16	8	8	52	48
1969	16	8	7	53	47
1970	15	8	7	52	48
1971	16	8	7	52	48
1972	16	9	8	54	46
1973	17	9	8	54	46
1974	17	9	8	52	48
1975	19	10	9	51	49
1976	21	10	10	50	50
1977	23	12	12	51	49
1978	26	13	13	50	50
1979	28	14	14	49	51
1980	30	15	15	50	50
1981	33	18	15	56	44
1982	36	22	14	61	39
1983	38	25	14	64	36
1984	44	29	15	66	34
1985(Est.) ..	50	34	16	68	32
1986(Est.) ..	58	42	16	72	28

Note: Detail may not add to totals due to rounding. Estimates given for 1986 may change significantly as the result of congressional action on agency budget requests Data for 1960-77 are shown in obligations; data for 1978-83 are shown in budget authority.

SOURCE: Executive Office of the President, Office of Management and Budget, "Special Analysis K," *Budget of the U. S. Government, 1986*, 1985.

See figure 2-10.

Science Indicators—1985

Appendix table 2-12. Federal funds[1] for R&D, by budget function: 1971-86

Function	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
	Million dollars															
Total	$15,542.5	$16,495.9	$16,800.2	$17,410.1	$19,038.8	$20,779.7	$23,450.0	$25,976.0	$28,208.0	$29,773.0	$33,735.0	$36,115.0	$38,768.0	$44,214.0	$50,479.0	$58,257.0
National defense	8,109.9	8,901.6	9,001.9	9,015.8	9,679.3	10,429.7	11,863.8	12,899.4	13,791.0	14,946.4	18,413.0	22,070.0	24,936.0	29,287.0	34,332.0	42,360.0
Health	1,287.8	1,546.7	1,585.0	2,068.6	2,170.2	23,502.6	2,628.5	2,967.7	3,401.3	3,694.3	3,870.8	3,869.0	4,298.0	4,779.0	5,408.0	5,108.0
Space research & technology	3,048.0	2,931.8	2,823.9	2,701.8	2,764.0	3,129.9	2,832.5	2,939.0	3,136.0	2,738.0	3,111.0	2,584.2	2,134.0	2,300.0	1,693.0	3,144.0
Energy	555.8	574.0	629.7	759.2	1,363.4	1,648.5	2,561.8	3,134.4	3,461.4	3,603.2	3,501.4	3,012.0	2,578.0	2,581.0	2,401.0	2,183.0
General science	512.5	625.3	657.6	749.4	813.3	857.7	973.8	1,050.2	1,119.1	1,232.6	1,340.0	1,359.0	1,502.0	1,676.0	1,873.0	1,990.0
Transportation	727.9	558.2	571.5	693.4	634.9	630.5	708.4	767.5	798.2	887.5	869.5	791.0	876.0	1,040.0	1,051.0	952.0
Natural resources & environment	415.5	478.5	553.8	516.0	624.3	683.0	753.1	903.9	1,009.6	999.3	1,060.5	965.0	952.0	963.0	1,033.0	905.0
Agriculture	259.0	294.4	308.1	313.1	341.8	382.5	456.7	501.3	551.6	585.3	658.5	692.7	745.0	762.0	819.0	778.0
Education, training, employment & social services	215.4	235.3	290.4	236.4	238.6	254.8	230.1	345.1	353.5	468.0	298.4	228.0	189.0	200.0	215.0	210.0
International affairs	31.9	28.6	28.3	23.8	29.0	42.4	66.3	57.2	116.8	127.3	160.0	165.0	177.0	192.0	217.0	225.0
Veterans benefits & services	62.9	69.1	74.3	84.8	94.8	97.7	107.0	111.1	122.8	125.8	142.9	139.2	157.0	218.0	193.0	187.0
Commerce & housing credit	89.5	49.7	50.2	50.8	64.9	68.7	70.5	76.7	92.7	102.1	105.5	103.9	106.9	110.0	116.0	106.0
Income security	144.9	106.3	106.3	70.9	71.9	48.3	55.2	67.3	56.8	77.2	42.6	31.6	32.0	26.0	25.0	24.0
Administration of justice	10.4	23.4	33.2	34.7	44.3	48.3	29.9	43.7	46.5	45.1	33.8	30.9	37.0	24.0	45.0	40.0
Community & regional development	64.6	65.8	78.4	82.1	92.5	108.5	100.9	91.9	127.3	119.4	104.3	62.5	44.0	46.0	43.0	28.0
General government	6.6	7.6	7.4	9.3	11.7	11.9	12.6	20.3	23.2	22.0	22.1	10.0	5.9	8.0	17.0	18.0
	Million constant 1972 dollars															
Total[2]	$16,254.4	$16,495.9	$16,084.4	$15,536.4	$15,446.0	$15,756.5	$16,659.6	$17,279.3	$17,256.8	$16,762.2	$17,269.9	$17,252.7	$17,814.5	$19,571.5	$21,546.4	$23,901.3
National defense	8,481.4	8,901.6	8,618.4	8,045.5	7,852.8	7,908.5	8,428.4	8,580.7	8,436.9	8,414.8	9,426.1	10,543.2	11,458.5	12,964.0	14,654.0	17,379.2
Health	1,346.8	1,546.7	1,517.5	1,846.0	1,760.7	17,821.2	1,867.4	1,974.1	2,080.8	2,079.9	1,981.6	1,848.3	1,975.0	2,115.4	2,308.3	2,095.7
Space research & technology	3,187.6	2,931.8	2,703.6	2,411.0	2,242.4	2,373.3	2,011.7	1,955.0	1,918.5	1,541.5	1,592.6	1,234.5	980.6	1,018.1	722.6	1,289.9
Energy	581.3	574.0	602.9	677.5	1,106.1	1,250.0	1,820.0	2,085.0	2,117.6	2,028.6	1,792.5	1,438.9	1,184.6	1,142.5	1,024.8	895.6
General science	536.0	625.3	629.6	668.7	659.8	650.4	691.8	698.6	684.6	694.0	686.0	649.2	690.2	741.9	799.5	816.4
Transportation	761.2	558.2	547.2	618.8	515.1	478.1	503.3	510.5	488.3	499.7	445.1	377.9	402.5	460.4	448.6	390.6
Natural resources & environment	434.5	478.5	530.2	460.5	506.5	517.9	535.0	601.3	617.6	562.6	542.9	461.0	437.5	426.3	440.9	371.3
Agriculture	270.9	294.4	295.0	279.4	277.3	290.0	324.5	333.5	337.5	329.5	337.1	330.9	342.3	337.3	349.6	319.2
Education, training, employment & social services	225.3	235.3	278.0	211.0	193.6	193.2	163.5	229.6	216.3	263.5	152.8	108.9	86.8	88.5	91.8	86.2
International affairs	33.4	28.6	27.1	21.2	23.5	32.2	47.1	38.0	71.5	71.7	81.9	78.8	81.3	85.0	92.6	92.3
Veterans benefits & services	65.8	69.1	71.1	75.7	76.9	74.1	76.0	73.9	75.1	70.8	73.2	66.5	72.1	96.5	82.4	76.7
Commerce & housing credit	93.6	49.7	48.1	45.3	52.7	52.1	50.1	51.0	56.7	57.5	54.0	49.6	49.1	48.7	49.5	43.5
Income security	151.5	106.3	101.8	63.3	58.3	36.6	39.2	44.8	34.7	43.5	21.8	15.1	14.7	11.5	10.7	9.8
Administration of justice	10.9	23.4	31.8	31.0	35.9	36.6	21.2	29.1	28.4	25.4	17.3	14.8	17.0	10.6	19.2	16.4
Community & regional development	67.6	65.8	75.1	73.3	75.0	82.3	71.7	61.1	77.9	67.2	53.4	29.9	20.2	20.4	18.4	11.5
General government	6.9	7.6	7.1	8.3	9.5	9.0	9.0	13.5	14.3	12.4	11.3	4.8	2.7	3.5	7.3	7.4

[1] Listed in descending order of 1986 budget authority. Data for the period 1971-77 are shown in obligations; data for 1978-84 are shown in budget authority.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

Note: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Federal R&D Funding by Budget Function, Fiscal Years 1984-86*, 1985, and earlier years.

See figures 2-9 and 2-12.

Appendix table 2-13. Federal obligations for basic research, by agency: 1967-86

Year	All agencies	DOE	DOD	NIH	NASA	NSF	All other agencies
	Million dollars						
1967	$1,846	$302	$284	$427	$328	$329	$176
1968	1,841	282	264	451	321	252	271
1969	1,945	285	276	454	380	248	302
1970	1,926	286	317	444	358	245	276
1971	1,980	277	322	504	327	273	277
1972	2,187	268	329	586	332	368	304
1973	2,232	275	307	593	350	392	315
1974	2,388	269	303	775	306	415	320
1975	2,588	313	300	829	309	486	351
1976	2,767	346	327	920	293	524	357
1977	3,259	389	373	1,033	414	625	425
1978	3,699	441	410	1,181	480	678	509
1979	4,193	463	472	1,464	513	733	548
1980	4,674	523	540	1,642	559	815	595
1981	5,041	586	604	1,767	531	897	656
1982	5,482	642	687	2,021	536	916	680
1983	6,260	767	785	2,313	617	939	779
1984	7,067	830	849	2,625	755	1,132	876
1985 (Est.)	7,787	916	830	3,022	776	1,273	970
1986 (Est.)	7,875	938	964	2,845	835	1,365	928
	Million constant 1972 dollars[2]						
1967	$2,324	$380	$358	$538	$413	$414	$222
1968	2,237	343	321	548	390	306	329
1969	2,257	331	320	527	441	288	350
1970	2,116	314	348	488	393	269	303
1971	2,071	290	337	527	342	286	290
1972	2,187	268	329	586	332	368	304
1973	2,137	263	294	568	335	375	302
1974	2,131	240	270	692	273	370	286
1975	2,100	254	243	673	251	394	285
1976	2,098	262	248	698	222	397	271
1977	2,315	276	265	734	294	444	302
1978	2,461	293	273	786	319	451	339
1979	2,565	283	289	896	314	448	335
1980	2,631	294	304	924	315	459	335
1981	2,581	300	309	905	272	459	336
1982	2,619	307	328	965	256	438	325
1983	2,877	352	361	1,063	284	459	358
1984	3,128	367	376	1,162	334	501	388
1985 (Est.)	3,324	391	354	1,290	331	543	414
1986 (Est.)	3,231	385	396	1,167	343	560	381

[1] Atomic Energy Commission, 1967-1973; Energy Research and Development Administration, 1974-1976; Department of Energy 1977-present.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *Federal Funds for Reseach and Development: Fiscal Years 1983, 1984, and 1985, vol. XXXIII* (NSF 84-336), and earlier volumes.

See figure 2-13.

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Appendix table 2-14. Federal obligations for basic research, by field of science: 1967-86

Field	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
	Million dollars																			
All fields	$1,846	$1,841	$1,945	$1,926	$1,980	$2,187	$2,232	$2,388	$2,588	$2,767	$3,259	$3,698	$4,193	$4,674	$5,041	$5,482	$6,260	$7,076	$7,787	$7,875
Life sciences	706	716	717	697	747	868	888	1,032	1,116	1,222	1,383	1,588	1,892	2,054	2,224	2,526	2,796	3,288	3,766	3,631
Biological & agricultural	419	496	504	485	519	597	609	692	747	818	934	1,079	1,279	1,339	1,462	1,675	1,850	2,175	2,498	2,422
Medical	233	206	197	199	211	246	253	318	342	374	415	468	560	657	706	793	882	1,015	1,154	1,101
Other life sciences	53	13	15	13	17	25	27	23	27	29	35	42	52	58	55	58	64	98	113	108
Environmental sciences[1]	209	199	235	243	261	263	273	292	281	294	388	451	457	522	533	520	560	657	665	704
Physical sciences	596	589	651	601	593	637	628	650	709	721	890	941	1,050	1,221	1,325	1,394	1,557	1,728	1,882	2,003
Chemistry	118	113	119	127	110	141	146	149	159	168	209	203	225	257	298	312	326	403	421	433
Physics	349	353	351	339	351	362	351	360	379	388	467	519	536	668	735	791	888	921	1,025	1,114
Astronomy	107	110	174	131	124	129	122	133	163	160	193	210	281	279	274	271	324	380	417	434
Other physical sciences	22	13	7	5	8	6	10	7	8	5	21	10	9	16	17	20	19	24	18	23
Psychology	53	47	47	48	46	51	45	46	59	46	56	84	75	84	91	90	99	108	120	124
Mathematics & computer sciences[2]	64	66	54	59	55	67	60	53	62	{43 39	52 31	56 42	60 44	67 49	79 61	91 74	100 96	114 127	125 133	139 143
Engineering	153	153	152	202	191	206	221	215	263	273	338	376	435	465	526	610	665	845	876	909
Social sciences	55	60	72	64	70	80	80	75	74	86	96	124	130	147	137	120	137	133	143	140
Other sciences	10	11	17	11	16	16	36	26	26	43	26	35	50	64	65	56	73	69	77	81

[1] Includes atmospheric sciences, geological sciences, oceanography and other environmental sciences

[2] Includes mathematics and computer sciences, not elsewhere classified

SOURCES: National Science Foundation, *Federal Funds for Research and Development, Fiscal Years 1983, 1984, and 1985, Vol. XXXIII* (NSF 84-336), and detailed historical data

See figure 2-14

Appendix table 2-15. Distribution of Federal agency obligations for basic research by performer: 1976, 1984, and 1985

Agency	Total	Federal intramural laboratories	Industry[1]	Universities and colleges	Other performers[2]
	Percent				
Total					
1976	100.0	28.4	6.9	48.5	16.2
1984	100.0	26.3	6.9	50.0	16.8
1985 (Est.)	100.0	25.2	6.6	51.6	16.6
1986 (Est.)	100.0	25.0	6.8	51.3	16.9
NIH					
1976	100.0	20.3	3.3	65.2	11.2
1984	100.0	18.3	1.0	66.0	14.7
1985 (Est.)	100.0	18.0	1.1	66.8	14.1
1986 (Est.)	100.0	17.6	1.1	66.7	14.6
NSF					
1976	100.0	11.1	1.6	74.8	12.5
1984	100.0	11.5	2.3	73.5	12.7
1985 (Est.)	100.0	11.4	2.3	74.2	12.1
1986 (Est.)	100.0	10.6	2.6	74.4	12.4
DOD					
1976	100.0	49.5	12.6	34.2	2.9
1984	100.0	35.8	10.8	47.8	5.6
1985 (Est.)	100.0	35.1	10.4	49.1	5.4
1986 (Est.)	100.0	35.5	10.3	48.7	5.4
DOE[3]					
1976	100.0	0.0	12.0	19.7	68.3
1984	100.0	1.4	12.6	22.2	63.8
1985 (Est.)	100.0	1.4	13.2	22.8	62.6
1986 (Est.)	100.0	1.9	12.8	22.6	62.7
NASA					
1976	100.0	50.1	23.4	22.9	3.6
1984	100.0	45.7	28.4	19.7	6.2
1985 (Est.)	100.0	43.2	27.1	22.9	6.8
1986 (Est.)	100.0	41.6	25.8	24.8	7.8
Other					
1976	100.0	65.8	1.0	28.6	4.6
1984	100.0	67.5	2.5	26.0	4.1
1985 (Est.)	100.0	65.2	3.5	27.3	4.0
1986 (Est.)	100.0	66.3	4.0	26.4	3.3

[1] Includes FFRDC's administered by this sector.

[2] Includes FFRDC's administered by university sector and other nonprofit institutions sector.

[3] Energy research and development administration in 1976.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Fiscal years 1967-85, 1985*.

Appendix table 2-16. Reimbursed and unreimbursed costs incurred for IR&D[1]: 1976-83

Type of IR&D costs	1976	1977	1978	1979	1980	1981	1982	(Est.) 1983
	Million dollars							
Total IR&D costs incurred by industry	$1,388	$1,560	$1,788	$2,104	$2,373	$2,796	$3,654	$3,930
Accepted by the Government under IR&D program	1,061	1,199	1,365	1,517	1,728	2,039	2,821	2,929
By DOD	544	598	643	708	812	1,056	1,338	1,579
By NASA	41	46	49	54	57	66	67	76
Unreimbursed	476	555	673	755	859	917	1,416	1,274
Not accepted under IR&D program	327	361	423	587	645	757	833	1,001

[1] Independent research and development.

SOURCES: National Science Board, *Science Indicators, 1980*; Annual Defense Contract Audit Agency Report, *Summary of IR&D and B&P Costs Incurred by Major Defense Contractors*; and NASA, unpublished data.

See figure 2-17.

Science Indicators—1985

Appendix table 2-17. DOD and NASA reimbursements as a percent of total DOD and NASA R&D and as a percent of DOD and NASA R&D performed by industry: 1976-83

Year	DOD and NASA IR&D reimbursement	DOD and NASA R&D obligations: Total	DOD and NASA R&D obligations: to industry[1]	IR&D as a percent of: DOD and NASA R&D total[2]	IR&D as a percent of: DOD & NASA R&D performed by industry[2]
	Million dollars			Percent	
				(a)	(b)
1976	$585	$13,102	$8,143	4.5	7.2
1977	644	14,134	9,108	4.6	7.1
1978	692	14,887	9,458	4.6	7.3
1979	763	16,084	10,079	4.7	7.6
1980	866	17,215	11,038	5.0	7.8
1981	1,122	20,102	13,027	5.6	8.6
1982	1,405	23,700	15,376	5.9	9.1
1983 (est.)	1,655	25,541	16,072	6.5	10.3

[1] Includes R&D performed by Federally Funded Research and Development Centers administered by the industrial sector.

[2] Percentages calculated as follows: numerator in (a) is total DOD and NASA IR&D reimbursements, and denominator is total NASA and DOD R&D including IR&D; numerator in (b) is total DOD and NASA IR&D reimbursements, and denominator is NASA and DOD R&D performed by industry, including IR&D.

SOURCE: Annual Defense Contract Audit Agency Report, *Summary of IR&D and B&P Cost Incurred by Major Defense Contractors*; NASA, unpublished data; and NSF, *Federal Funds for R&D, Detailed Historical Tables* (1985).

Science Indicators—1985

Appendix table 2-18. USDA-SAES[1] and private sector agricultural research expenditures: 1969, 1979, and 1981

	1969[2]	1979[2]	1981
	Million dollars		
Total	1,047	2,980	3,776
Private sector[3]	581	1,782	2,242
Food kindred products	199	480	719
Agricultural chemicals	104	292	487
Other	278	1,010	1,036
Public sector	466	1,198	1,534
SAES[1]	259	718	943
SAES-USDA[4]	79	189	223
USDA[5]	128	291	368

[1] State agricultural experiment stations.

[2] Estimates generated by Evenson (1983).

[3] Includes private sector expenditures for food and kindred products, wood products, agriculture chemicals, farm machinery and equipment and 20 percent of drugs and medicines.

[4] State agricultural experiment stations associated with the USDA.

[5] Other USDA research agencies.

SOURCES: Evenson (1983); U.S. Department of Agriculture, *Current Research Information System Inventory of Agricultural Research, FY 1981* (1983); and NSF, *R&D in Industry 1981* (NSF 83-325).

Science Indicators—1985

Appendix table 2-19. Federal obligations for basic research in agriculture: 1980-1986

	1980	1981	1982	1983	1984	(Est.) 1985	(Est.) 1986
	Million dollars						
Total	$277.6	$315.6	$334.3	$367.7	$396.2	$448.1	$426.0
USDA	275.7	314.1	330.8	362.0	392.6	440.3	418.5
ARS[1]	157.8	186.4	192.9	215.3	240.6	250.6	250.6
CSR[2]	75.2	83.9	91.3	98.8	99.6	132.0	119.3
Other USDA	42.7	43.8	46.6	47.9	52.4	57.7	48.6
Other Federal[3]	1.9	1.5	3.5	5.7	3.6	7.8	7.5

[1] Agriculture Research Service.

[2] Cooperative State Research Service.

[3] Includes support provided for basic research in the agricultural sciences by agencies other than USDA.

SOURCE: National Science Foundation, *Federal Funds for Research and Development: Detailed Historical Tables* (1984).

Science Indicators—1985

Appendix table 2-20. Average number of biotechnology research projects and personnel commitments at State Agricultural Experiment Stations: 1982

	1982
Average number of FTE[1] investigators	156.3
Average number of biotechnology projects	13.8
Average number of FTE[1] biotechnology personnel	
Faculty	6.7
Students	10.5
Staff	11.9

[1] FTE = Full-time equivalent.

Note: 1982 averages based on information from 42 SAES.

SOURCE: National Association of State Universities and Land-Grant Colleges, *Emerging Biotechnologies in Agriculture: Issues and Policies* (1983).

Science Indicators—1985

Appendix table 3-1. Scientists and engineers as a percent of total U.S. work force, by selected years

Year	(Percent)
1976	2.6
1978	2.7
1980	2.9
1982	3.3
1983	3.4

SOURCE: Based on National Science Foundation, *U.S. Scientists and Engineers: 1982* (NSF 84-319) and unpublished data; and *Economic Report of the President, 1984*, pp.254.

See figure 3-1.

Science Indicators—1985

Appendix table 3-2. Average annual percent increases in employment in science and engineering, and other economic variables: 1976-83

	1976-80	1980-83
Scientists and engineers	5.2	6.6
Scientists	5.4	8.8
Engineers	5.1	5.0
Professional workers	3.4	2.7
U.S. employment	3.3	−0.2
Gross National Product (in constant dollars)	3.2	1.3

SOURCES: National Science Foundation, *U.S. Scientists and Engineers: 1982* (NSF 84-319) and unpublished data; U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings*, January 1984, vol. 31, no. 1, pp. 14 and 176; and *Economic Report of the President*, 1984, pp. 222 and 254.

See figure 3-2.

Science Indicators—1985

Appendix table 3-3. Employment status of scientists and engineers, by field and sex: 1976, 1980, and 1983

Field and sex	Total employed			Employed in S/E		
	1976	1980	1983	1976	1980	1983
Total, all S E fields	2,331,200	2,860,400	3,465,900	2,122,100	2,542,700	3,049,700
Men	2,131,600	2,544,800	3,026,100	1,947,200	2,269,900	2,695,100
Women	199,700	315,600	439,800	174,900	272,800	354,600
Total scientists	959,500	1,184,500	1,525,900	843,800	1,032,800	1,244,000
Men	781,300	918,000	1,149,300	689,100	806,200	948,200
Women	178,200	266,500	376,600	154,700	226,600	295,800
Physical scientists	188,900	215,200	235,900	154,900	166,300	218,400
Men	172,700	194,500	212,800	143,600	151,700	197,100
Women	16,200	20,800	23,100	11,300	14,500	21,300
Mathematical scientists	48,600	64,300	86,700	43,800	57,300	74,800
Men	37,100	46,400	57,700	33,700	42,100	48,700
Women	11,500	13,000	29,000	10,000	15,200	26,100
Computer specialists	119,000	207,800	349,100	116,000	196,700	252,400
Men	98,400	149,900	251,700	95,100	147,600	181,400
Women	20,600	57,900	97,400	20,900	49,100	71,000
Environmental scientists	54,800	77,600	95,100	46,600	63,100	90,200
Men	50,900	66,800	80,500	44,000	54,700	76,400
Women	3,900	10,700	14,600	2,600	8,400	13,800
Life scientists	213,500	287,500	368,400	198,200	267,300	325,600
Men	179,600	234,400	288,100	167,700	218,400	256,400
Women	33,900	53,100	80,300	30,500	48,900	69,200
Psychologists	112,500	128,100	143,500	103,700	112,500	109,300
Men	76,900	79,400	84,200	71,600	70,400	67,300
Women	35,600	48,700	59,300	32,000	42,100	42,100
Social scientists	222,300	204,000	247,200	180,500	169,700	173,200
Men	165,700	146,700	174,400	133,200	121,300	120,900
Women	56,600	57,200	72,800	47,300	48,300	52,300
Total engineers	1,371,700	1,675,900	1,940,000	1,278,300	1,509,900	1,805,700
Men	1,350,300	1,626,700	1,876,700	1,258,100	1,463,600	1,746,900
Women	21,400	49,200	63,300	20,200	46,200	58,800
Astronautical aeronautical	56,800	69,500	84,700	55,700	65,000	80,900
Men	56,400	68,300	83,100	55,100	63,700	79,400
Women	400	1,200	1,600	600	1,300	1,500
Chemical	77,500	94,500	114,900	76,400	89,000	107,800
Men	75,000	90,000	107,600	73,700	84,500	100,900
Women	2,500	4,500	7,300	2,800	4,500	6,900
Civil	188,200	232,100	271,800	182,800	217,000	256,600
Men	182,800	226,300	266,300	178,100	211,500	251,200
Women	5,400	5,800	5,500	4,800	5,500	5,400
Electrical electronics	283,000	383,100	470,500	267,900	357,400	444,500
Men	281,400	375,400	461,100	266,500	350,200	436,100
Women	1,600	7,600	9,400	1,400	7,200	8,400
Mechanical	276,200	322,600	371,500	272,800	308,800	347,100
Men	273,900	316,000	366,000	270,600	302,000	342,000
Women	2,300	6,600	5,400	2,200	6,800	5,100
Other engineers	490,000	574,100	626,500	422,700	472,600	568,900
Men	480,900	550,600	592,600	414,200	451,600	537,400
Women	9,100	23,500	33,900	8,500	21,000	31,500

Note: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview* (NSF 85-302)

See figures 3-3, 3-6, 3-17, 3-18, 3-19, 3-28 and 3-29

Appendix table 3-4. Employment status of scientists and engineers, by field and race: 1976, 1980, and 1983

Field and race	Total employed			Employed in S/E		
	1976	1980	1983	1976	1980	1983
Total, all S/E fields	2,331,200	2,860,400	3,465,900	2,122,100	2,542,700	3,049,700
White	2,141,900	2,644,900	3,180,000	1,949,700	2,349,700	2,800,300
Black	38,100	57,600	82,800	34,900	50,900	67,900
Asian	106,600	121,000	145,300	98,500	112,000	132,200
Other	44,600	37,000	57,800	38,900	30,100	49,300
Total scientists	959,500	1,184,500	1,525,900	843,800	1,032,800	1,244,000
White	870,900	1,097,000	1,401,000	764,200	957,900	1,144,500
Black	21,400	30,500	47,400	19,400	26,000	35,200
Asian	48,500	41,500	52,400	43,100	37,500	44,500
Other	18,700	15,400	25,000	17,100	11,400	19,700
Physical scientists	188,900	215,200	235,900	154,900	166,300	218,400
White	172,400	201,200	221,000	141,200	155,600	205,300
Black	3,200	3,400	3,700	2,400	2,400	3,000
Asian	7,600	8,800	8,500	6,400	7,100	7,800
Other	5,700	1,800	2,700	4,900	1,200	2,300
Mathematical scientists	48,600	64,300	86,700	43,800	57,300	74,800
White	44,200	59,200	79,000	39,400	52,600	67,600
Black	2,600	2,900	3,900	2,500	2,500	3,700
Asian	1,600	2,100	3,100	1,700	2,100	2,800
Other	200	200	800	200	200	700
Computer specialists	119,000	207,800	349,100	116,000	196,700	252,400
White	110,700	192,000	315,900	108,000	181,500	227,500
Black	1,600	4,700	11,700	1,500	4,300	8,200
Asian	4,000	9,900	16,000	3,900	9,700	12,700
Other	2,700	1,300	5,500	2,600	1,200	4,000
Environmental scientists	54,800	77,600	95,100	46,600	63,100	90,200
White	48,300	70,000	88,700	40,700	57,700	84,000
Black	2,000	700	600	1,800	800	400
Asian	3,200	2,500	3,700	2,900	2,000	3,700
Other	1,200	4,400	2,100	1,200	2,700	2,100
Life scientists	213,500	287,500	368,400	198,200	267,300	325,600
White	200,700	270,300	346,100	186,100	250,700	306,200
Black	4,900	6,700	9,000	4,700	6,400	8,500
Asian	5,300	7,100	8,400	5,400	6,900	7,000
Other	2,500	3,400	4,800	2,000	3,400	3,900
Psychologists	112,500	128,100	143,500	103,700	112,500	109,300
White	105,100	121,600	135,100	97,100	107,400	104,200
Black	3,800	3,800	4,700	3,700	3,400	2,500
Asian	1,000	1,200	1,400	700	1,000	1,200
Other	2,600	1,500	2,200	2,100	800	1,500
Social scientists	222,300	204,000	247,200	180,500	169,700	173,200
White	189,400	182,800	215,300	151,600	152,600	149,700
Black	3,300	8,300	13,700	2,900	6,400	8,900
Asian	25,800	10,000	11,300	22,100	8,700	9,400
Other	3,800	2,900	7,000	3,900	2,000	5,200

(continued)

Table 3-4.(Continued)

Field and race	Total employed 1976	Total employed 1980	Total employed 1983	Employed in S/E 1976	Employed in S/E 1980	Employed in S/E 1983
Total engineers	1,371,700	1,675,900	1,940,000	1,278,300	1,509,900	1,805,700
White	1,271,000	1,547,800	1,779,000	1,185,500	1,391,700	1,655,800
Black	16,700	27,000	35,400	15,500	24,900	32,700
Asian	58,100	79,500	92,900	55,400	74,600	87,600
Other	25,900	21,600	32,800	21,900	18,700	29,600
Astronautical aeronautical	56,800	69,500	84,700	55,700	65,000	80,900
White	54,100	65,000	79,500	52,900	60,500	76,000
Black	300	1,100	1,400	300	1,200	1,300
Asian	1,600	2,200	2,800	1,700	2,100	2,800
Other	700	1,200	1,100	700	1,200	800
Chemical	77,500	94,500	114,900	76,400	89,000	107,800
White	72,200	86,400	103,500	71,100	81,300	97,100
Black	1,500	800	1,100	1,500	400	1,000
Asian	2,400	5,800	8,600	2,400	5,700	8,100
Other	1,400	1,500	1,700	1,400	1,500	1,600
Civil	188,200	232,100	271,800	182,800	217,000	256,600
White	165,700	209,100	243,400	162,500	194,900	230,100
Black	1,600	3,900	4,200	1,800	3,800	4,100
Asian	14,800	16,000	18,200	14,800	15,200	17,000
Other	6,100	3,100	6,000	3,700	3,100	5,400
Electrical electronics	283,000	383,100	470,500	267,900	357,400	444,500
White	262,500	346,500	425,200	248,800	323,600	401,600
Black	2,900	8,100	11,700	2,600	7,500	10,600
Asian	13,800	23,300	26,000	12,700	22,100	25,200
Other	3,800	5,100	7,600	3,800	4,200	7,000
Mechanical	276,200	322,600	371,500	272,800	308,800	347,100
White	258,700	302,000	345,400	255,300	288,900	322,600
Black	2,400	2,700	4,000	2,200	2,500	3,600
Asian	9,700	13,900	16,400	9,600	13,600	15,300
Other	5,500	3,900	5,700	5,700	3,900	5,500
Other engineers	490,000	574,100	626,500	422,700	472,600	568,900
White	457,800	538,700	582,000	394,900	442,400	528,300
Black	8,000	10,300	13,000	7,000	9,400	12,000
Asian	15,800	18,300	20,900	14,300	15,900	19,300
Other	8,500	6,700	10,600	6,500	4,900	9,300

NOTE: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview* (NSF 85-302).

Science Indicators—1985.

Appendix table 3-5. Employment status of Hispanic scientists and engineers, by field: 1983

Field	Total employed	Employed in S/E
Total, all S/E fields	74,100	61,800
Total scientists	30,100	21,900
Physical scientists	3,700	3,100
Mathematical scientists	1,600	1,400
Computer specialists	5,300	3,800
Environmental scientists	1,500	1,400
Life scientists	7,300	5,700
Psychologists	2,400	1,200
Social scientists	8,300	5,200
Total engineers	44,100	39,900
Aeronautical/astronautical	1,600	1,300
Chemical	3,200	2,700
Civil	8,400	7,900
Electrical/electronics	9,800	9,300
Industrial	2,800	2,400
Materials	300	300
Mechanical	7,200	6,400
Mining	100	100
Nuclear	200	200
Petroleum	900	800
Other engineers	9,600	8,400

Note: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview* (NSF 85-302).

Science Indicators—1985

Appendix table 3-6. Employment status of doctoral scientists and engineers, by field and sex: 1973, 1981 and 1983

Field and sex	Total employed			Employed in S/E		
	1973	1981	1983	1973	1981	1983
Total, all S/E fields	220,300	344,000	369,300	208,300	314,500	327,400
Men	203,400	303,000	320,500	192,600	277,800	284,900
Women	16,900	41,000	48,900	15,700	36,800	42,500
Total scientists	184,600	286,900	307,800	173,800	261,400	271,200
Men	167,800	246,700	269,000	158,300	225,400	229,700
Women	16,800	40,200	47,800	15,500	36,000	41,500
Physical scientists	48,500	63,100	64,000	45,100	57,100	56,300
Men	46,600	59,300	59,800	43,400	53,800	52,700
Women	1,900	3,800	4,200	1,700	3,300	3,600
Mathematical scientists	12,100	15,600	16,400	11,800	14,100	14,300
Men	11,400	14,300	15,000	11,100	12,900	13,100
Women	800	1,300	1,400	700	1,200	1,200
Computer specialists	2,700	9,100	12,200	2,700	9,000	12,000
Men	2,600	8,400	10,900	2,600	8,300	10,700
Women	100	700	1,300	100	700	1,300
Environmental scientists	10,300	15,900	16,500	10,100	15,300	15,700
Men	10,100	15,100	15,600	9,900	14,500	14,800
Women	300	900	900	300	800	900
Life scientists	56,700	84,900	92,800	54,800	80,700	85,900
Men	50,600	71,600	76,600	49,000	68,300	71,000
Women	6,100	13,300	16,200	5,800	12,500	14,900
Psychologists	24,800	42,800	46,600	23,500	39,400	41,700
Men	20,000	31,100	33,000	19,000	28,700	29,500
Women	4,800	11,700	13,700	4,500	10,600	12,200
Social scientists	29,400	55,500	59,300	25,900	45,800	45,300
Men	26,500	47,000	49,300	23,400	38,900	37,900
Women	2,900	8,600	10,100	2,500	6,900	7,500
Total engineers	35,800	57,000	61,500	34,400	53,200	56,200
Men	35,600	56,300	60,500	34,300	52,400	55,200
Women	100	800	1,100	100	700	1,000
Aeronatical/astronautical	1,700	2,500	3,700	1,600	2,200	3,400
Men	1,700	2,500	3,600	1,600	2,200	3,300
Women	(1)	(1)	100	(1)	(1)	100
Chemical	4,500	7,100	7,000	4,200	6,400	6,100
Men	4,500	7,100	6,900	4,200	6,300	6,000
Women	(1)	100	100	(1)	100	100
Civil	3,100	6,100	5,300	3,000	5,500	5,000
Men	3,100	6,000	5,200	3,000	5,400	4,900
Women	(1)	100	100	(1)	100	100
Electrical/electronics	7,100	10,600	12,700	6,800	10,000	11,400
Men	7,000	10,500	12,500	6,800	9,900	11,200
Women	(1)	100	200	(1)	100	200
Mechanical	3,300	5,400	5,700	3,100	5,000	5,100
Men	3,300	5,300	5,600	3,100	4,900	5,100
Women	(1)	(1)	100	(1)	(1)	100
Nuclear	1,300	2,100	2,300	1,200	2,000	2,200
Men	1,300	2,000	2,300	1,200	2,000	2,200
Women	(1)	(1)	(1)	(1)	(1)	(1)
Other engineers	15,000	23,200	24,900	14,500	22,000	23,000
Men	14,900	22,800	24,400	14,400	21,700	22,500
Women	100	400	500	100	400	500

[1] Too few cases to estimate.

Note: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States*, biennial series, and unpublished data.

See figures 3-4 and 3-27.

Appendix table 3-7. Scientists and engineers, by field, sex, and type of employer: 1976 and 1983

Field and sex	Total		Business/industry		Educational institutions		Federal Government	
	1976	1983	1976	1983	1976	1983	1976	1983
Total, all S/E fields	2,331,200	3,465,900	1,456,500	2,330,200	287,600	415,500	219,200	306,100
Men	2,131,600	3,026,100	1,385,100	2,098,400	232,400	315,400	200,600	266,500
Women	199,700	439,800	71,400	231,800	55,200	100,100	18,500	39,500
Total scientists	959,500	1,525,900	430,300	782,100	248,000	362,500	110,700	167,400
Men	781,300	1,149,300	373,200	602,300	194,000	265,000	93,600	131,500
Women	178,200	376,600	57,000	179,800	54,000	97,400	17,000	35,900
Physical scientists	188,900	235,900	105,400	140,900	39,100	50,000	22,400	25,000
Men	172,700	212,800	97,200	127,500	34,400	44,700	20,900	23,200
Women	16,200	23,100	8,200	13,400	4,700	5,300	1,500	1,800
Mathematical scientists	48,600	86,700	15,000	28,700	21,100	40,100	9,000	12,200
Men	37,100	57,700	12,000	20,900	15,700	27,500	7,200	6,100
Women	11,500	29,000	2,900	7,700	5,500	12,600	1,800	6,100
Computer specialists	119,000	349,100	86,800	276,500	6,900	19,700	9,300	24,500
Men	98,400	251,700	72,300	201,400	5,800	14,100	7,700	16,100
Women	20,600	97,400	14,500	75,100	1,100	5,600	1,600	8,400
Environmental scientists	54,800	95,100	30,900	59,100	6,100	11,600	10,100	16,400
Men	50,900	80,500	28,900	50,600	5,200	9,700	9,300	13,600
Women	3,900	14,600	2,000	8,500	900	2,000	800	2,800
Life scientists	213,500	368,400	71,500	121,700	63,300	119,200	39,300	62,200
Men	179,600	288,100	63,600	94,900	50,800	89,000	34,200	53,300
Women	33,900	80,300	7,900	26,800	12,600	30,300	5,200	9,000
Psychologists	112,500	143,500	26,400	47,000	43,800	54,100	5,200	3,400
Men	76,900	84,200	20,400	26,800	29,900	32,100	3,100	2,300
Women	35,600	59,300	6,000	20,200	13,900	22,100	2,100	1,100
Social scientists	222,300	247,200	94,400	108,300	67,700	67,700	15,300	23,600
Men	165,700	174,400	78,800	80,200	52,300	48,100	11,200	16,900
Women	56,600	72,800	15,600	28,100	15,500	19,500	4,000	6,600
Total engineers	1,371,700	1,940,000	1,026,200	1,548,100	39,600	53,000	108,500	138,700
Men	1,350,300	1,876,700	1,011,900	1,496,100	38,400	50,300	107,000	135,000
Women	21,400	63,300	14,300	52,000	1,200	2,700	1,500	3,600
Astronautical/aeronautical	56,800	84,700	40,300	62,800	1,800	2,400	11,100	14,000
Men	56,400	83,100	39,900	61,700	1,800	2,200	11,100	13,900
Women	400	1,600	400	1,000	(1)	200	(1)	100
Chemical	77,500	114,900	69,200	103,600	900	3,100	2,700	3,100
Men	75,000	107,600	67,100	96,900	900	3,000	2,600	2,900
Women	2,500	7,300	2,100	6,800	(1)	100	100	100
Civil	188,200	271,800	88,800	165,500	5,500	6,000	21,300	25,600
Men	182,800	266,300	86,900	162,200	5,200	5,800	20,900	24,900
Women	5,400	5,500	1,900	3,300	300	200	400	800
Electrical/electronics	283,000	470,500	223,500	380,500	10,800	14,300	28,300	41,900
Men	281,400	461,100	222,400	372,900	10,700	13,600	28,300	41,300
Women	1,600	9,400	1,100	7,600	100	700	(1)	600
Mechanical	276,200	371,500	230,400	322,500	8,700	10,300	15,400	18,800
Men	273,900	366,000	228,400	317,900	8,600	9,800	15,100	18,700
Women	2,300	5,400	1,900	4,500	100	600	300	100
Other engineers	490,000	626,500	374,000	513,200	11,900	16,800	29,600	35,200
Men	480,900	592,600	367,100	484,500	11,200	15,900	29,000	33,300
Women	9,100	33,900	6,900	28,700	600	900	700	1,900

[1] Too few cases to estimate.

Note: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview* (NSF 85-302)

See figures 3-7, 3-8, & 3-21.

Appendix table 3-8. Employed doctoral scientists and engineers, by field, sex, and type of employer: 1973 and 1983

Field and sex	Total		Business industry		Educational institutions		Federal Government	
	1973	1983	1973	1983	1973	1983	1973	1983
Total, all S/E fields	220,300	369,300	53,400	113,500	129,300	196,100	18,200	25,800
Men	203,400	320,500	52,000	103,300	117,200	166,700	17,200	23,300
Women	16,900	48,800	1,400	10,200	12,100	29,300	1,000	2,500
Total scientists	184,600	307,800	35,600	79,000	116,300	175,700	15,500	22,000
Men	167,800	260,000	34,300	69,400	104,300	146,700	14,500	19,600
Women	16,800	47,800	1,300	9,600	12,100	29,000	1,000	2,400
Physical scientists	48,500	64,000	19,700	28,700	22,000	27,900	4,100	4,300
Men	46,600	59,800	19,300	27,300	20,700	25,800	4,000	4,000
Women	1,900	4,200	300	1,400	1,300	2,200	100	300
Mathematical scientists	12,100	16,400	900	2,000	10,500	13,200	500	800
Men	11,400	15,000	800	1,900	9,800	12,100	500	700
Women	800	1,400	(1)	200	700	1,200	(1)	100
Computer specialists	2,700	12,200	1,000	6,800	1,400	4,000	100	500
Men	2,600	10,900	1,000	6,100	1,300	3,700	100	500
Women	100	1,300	(1)	700	(1)	400	(1)	(1)
Environmental scientists	10,300	16,500	2,200	5,200	5,200	6,700	2,000	3,100
Men	10,100	15,600	2,200	4,900	5,000	6,300	1,900	2,900
Women	300	900	(1)	300	200	400	(1)	200
Life scientists	56,700	92,800	7,100	16,400	38,200	58,900	5,800	7,800
Men	50,600	76,600	6,800	14,600	33,700	47,400	5,400	6,900
Women	6,100	16,200	300	1,900	4,600	11,500	500	900
Psychologists	24,800	46,600	3,100	13,000	15,000	22,200	1,200	1,200
Men	20,000	33,000	2,600	8,900	12,200	15,800	1,000	1,000
Women	4,800	13,700	500	4,100	2,900	6,400	200	200
Social scientists	29,400	59,300	1,700	6,800	24,000	42,800	1,700	4,300
Men	26,500	49,300	1,600	5,700	21,600	35,700	1,600	3,600
Women	2,900	10,100	100	1,000	2,400	7,100	100	700
Total engineers	35,800	61,500	17,800	34,500	13,000	20,300	2,700	3,800
Men	35,600	60,500	17,700	33,900	13,000	20,000	2,700	3,800
Women	100	1,100	100	600	100	300	(1)	100
Aeronautical/astronautical	1,700	3,700	600	1,900	400	900	300	500
Men	1,700	3,600	600	1,900	400	900	300	500
Women	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)
Chemical	4,500	7,000	3,200	4,800	1,000	1,700	100	200
Men	4,500	6,900	3,200	4,700	1,000	1,700	100	200
Women	(1)	100	(1)	100	(1)	(1)	(1)	(1)
Civil	3,100	5,300	900	1,900	1,700	3,100	200	100
Men	3,100	5,200	900	1,900	1,700	3,100	200	100
Women	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)
Electrical/electronics	7,100	12,700	3,400	7,600	2,800	4,000	500	800
Men	7,000	12,500	3,400	7,500	2,800	3,900	500	800
Women	(1)	200	(1)	200	(1)	100	(1)	(1)
Materials	4,500	7,400	2,700	4,900	1,200	1,800	400	500
Men	4,400	7,300	2,700	4,800	1,200	1,800	300	500
Women	(1)	200	(1)	100	(1)	(1)	(1)	(1)
Mechanical	3,300	5,700	1,400	2,600	1,600	2,600	200	400
Men	3,300	5,600	1,400	2,600	1,600	2,500	200	300
Women	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)
Nuclear	1,300	2,300	700	1,400	300	700	200	100
Men	1,300	2,300	700	1,400	300	700	200	100
Women	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Systems design	2,000	3,900	1,000	2,300	600	900	200	300
Men	1,900	3,800	1,000	2,200	600	900	200	200
Women	(1)	100	(1)	100	(1)	(1)	(1)	(1)
Other engineers	8,600	13,600	3,900	7,200	3,300	4,700	800	1,100
Men	8,500	13,300	3,900	7,000	3,300	4,600	800	1,100
Women	(1)	300	(1)	100	(1)	100	(1)	(1)

[1] Too few cases to estimate.

Note: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States*, biennial series, and unpublished data.

Science Indicators—1985

Appendix table 3-9. Scientists and engineers, by field, sex, and primary work activity: 1976 and 1983

Field and sex	Total		Research		Development		Management of R&D	
	1976	1983	1976	1983	1976	1983	1976	1983
Total all S/E fields	2,331,200	3,465,900	217,100	347,700	438,400	718,300	220,000	288,200
Men	2,131,600	3,026,100	183,200	283,600	423,000	670,200	209,500	268,900
Women	199,700	439,800	33,900	64,100	15,400	48,100	10,400	19,300
Total scientists	959,500	1,525,900	165,800	268,900	65,200	132,500	88,300	115,600
Men	781,300	1,149,300	134,800	208,400	56,600	103,700	79,700	99,000
Women	178,200	376,600	31,000	60,500	8,600	28,800	8,600	16,600
Physical scientists	138,900	235,900	53,400	68,900	24,200	36,400	29,900	31,100
Men	172,700	212,800	47,700	61,700	23,000	33,300	29,300	30,100
Women	16,200	23,100	5,700	7,200	1,200	3,100	600	900
Mathematical scientists	48,600	86,700	5,700	9,800	2,600	4,300	6,200	8,100
Men	37,100	57,700	4,800	7,100	1,600	2,600	4,900	6,300
Women	11,500	29,000	900	2,700	1,000	1,600	1,300	1,800
Computer specialists	119,000	359,100	1,900	8,300	25,600	58,200	8,200	19,400
Men	98,400	251,700	1,500	6,100	20,100	42,200	7,400	15,400
Women	20,600	97,400	400	2,300	5,500	16,000	900	4,000
Environmental scientists	54,800	95,100	19,400	31,400	3,600	10,100	6,500	8,200
Men	50,900	80,500	16,500	24,700	3,500	8,300	6,400	7,500
Women	3,900	14,600	2,900	6,700	100	1,800	200	700
Life scientists	213,500	368,400	57,700	111,100	7,100	15,700	18,600	26,400
Men	179,600	288,100	44,500	82,700	6,400	11,400	17,600	23,600
Women	33,900	80,300	13,300	28,400	800	4,200	1,100	2,800
Psychologists	112,500	143,500	6,700	9,000	1,200	2,400	4,600	5,600
Men	76,900	84,200	4,700	5,300	1,200	1,400	3,900	3,800
Women	35,600	59,300	2,000	3,700	(1)	1,000	700	1,700
Social scientists	222,300	247,200	21,000	30,400	1,000	5,500	14,200	16,800
Men	165,700	174,400	15,100	20,800	900	4,400	10,300	12,200
Women	56,600	72,800	5,900	9,500	100	1,100	3,900	4,500
Total engineers	1,371,700	1,940,000	51,400	78,800	373,100	585,800	131,700	172,600
Men	1,350,300	1,876,700	48,400	75,200	366,400	566,500	129,800	169,900
Women	21,400	63,300	3,000	3,600	6,800	19,300	1,800	2,700
Astronautical/aeronautical	56,800	84,700	5,400	7,600	20,000	31,800	13,900	16,100
Men	56,400	83,100	5,300	7,400	19,700	31,200	13,900	16,000
Women	400	1,600	100	300	300	500	(1)	100
Chemical	77,500	114,900	4,400	6,200	24,000	40,700	8,600	11,000
Men	75,000	107,600	4,100	5,700	23,800	37,400	8,100	10,900
Women	2,500	7,300	300	500	200	3,200	500	100
Civil	188,200	271,800	3,400	5,200	31,000	45,500	6,000	9,900
Men	182,800	266,300	2,600	5,000	29,300	43,900	6,000	9,900
Women	5,400	5,500	800	200	1,700	1,600	(1)	100
Electrical/electronics	283,000	470,500	11,800	22,300	102,500	183,800	38,900	57,500
Men	281,400	461,100	11,800	21,600	101,900	180,100	38,700	57,000
Women	1,600	9,400	(1)	600	600	3,700	200	600
Mechanical	276,200	371,500	8,200	12,700	104,700	151,100	29,700	34,700
Men	273,900	366,000	8,100	12,400	104,100	148,800	28,700	34,400
Women	2,300	5,400	100	300	700	2,300	1,000	300
Other engineers	490,000	626,500	18,200	24,900	91,000	133,000	34,600	43,400
Men	480,900	592,600	16,500	23,100	87,700	125,200	34,400	41,700
Women	9,100	33,900	1,700	1,800	3,300	7,800	200	1,600

(continued)

Table 3-9. (Continued)

Field and sex	Management—other than R&D		Teaching		Production/inspection		Reporting/statistical work/computing	
	1976	1983	1976	1983	1976	1983	1976	1983
Total, all fields	467,100	598,300	163,300	236,900	253,000	442,300	107,700	334,700
Men	443,300	551,700	131,800	177,700	241,300	408,300	88,600	241,600
Women	23,800	46,600	31,500	59,200	11,700	34,000	19,100	93,100
Total scientists	175,100	234,900	141,300	205,400	58,500	106,800	70,300	254,200
Men	152,900	194,700	109,900	148,300	50,200	85,400	52,100	168,600
Women	22,300	40,200	31,400	57,100	8,300	21,400	18,100	85,700
Physical scientists	20,800	24,600	22,700	29,500	19,700	27,000	3,800	5,200
Men	19,000	23,000	20,300	26,200	17,600	22,800	3,000	4,100
Women	1,700	1,600	2,300	3,200	2,100	4,300	700	1,200
Mathematical scientists	7,600	10,900	17,400	32,200	2,000	2,400	4,500	15,700
Men	7,300	8,900	12,500	21,300	1,400	2,000	2,500	7,400
Women	300	2,000	5,000	10,800	600	400	2,000	8,400
Computer specialists	16,600	29,800	3,800	8,800	4,000	10,200	38,700	183,200
Men	15,400	25,200	2,900	5,600	3,100	7,600	31,700	126,300
Women	1,200	4,600	900	3,200	900	2,600	7,000	57,000
Environmental scientists	8,400	12,400	3,100	5,900	3,400	9,600	2,300	6,300
Men	8,400	11,700	2,700	4,700	3,300	8,900	2,100	5,000
Women	(1)	700	400	1,200	100	800	200	1,200
Life scientists	43,700	70,700	29,300	50,900	14,900	40,500	3,200	10,800
Men	39,100	61,800	23,300	38,400	12,800	31,700	2,400	7,200
Women	4,600	8,900	6,000	12,400	2,100	8,800	800	3,600
Psychologists	17,400	24,000	21,600	29,100	1,800	6,200	1,300	3,500
Men	13,500	15,500	14,300	18,100	1,300	3,800	700	1,500
Women	3,900	8,500	7,400	11,000	600	2,300	600	2,000
Social scientists	60,700	62,500	43,400	49,200	12,600	10,900	16,500	29,400
Men	50,100	48,500	34,000	34,000	10,700	8,700	9,800	17,100
Women	10,500	14,000	9,400	15,200	1,900	2,200	6,700	12,300
Total engineers	292,000	363,400	22,000	31,500	194,500	335,500	37,400	80,400
Men	290,500	357,100	21,900	29,400	191,100	322,900	36,400	73,000
Women	1,500	6,300	200	2,100	3,400	12,600	1,000	7,500
Astronautical/aeronautical	5,100	8,800	1,000	1,200	4,400	8,300	2,200	4,700
Men	5,100	8,800	1,000	1,100	4,300	7,900	2,200	4,500
Women	(1)	100	(1)	100	100	400	(1)	100
Chemical	20,000	22,800	600	1,500	10,300	19,800	1,400	3,300
Men	20,000	22,300	600	1,400	9,000	18,000	1,300	2,900
Women	(1)	500	(1)	100	1,300	1,800	100	500
Civil	58,800	79,200	2,300	3,600	38,400	55,300	6,100	11,200
Men	58,000	78,200	2,200	3,400	38,100	54,400	5,600	10,700
Women	800	1,000	100	200	300	900	400	500
Electrical/electronics	48,200	64,200	4,800	8,100	30,200	69,300	6,500	16,300
Men	48,200	63,500	4,800	7,600	30,000	67,700	6,500	15,500
Women	(1)	700	(1)	400	200	1,500	(1)	800
Mechanical	59,100	69,400	5,500	6,100	30,600	52,200	3,200	7,300
Men	59,100	68,900	5,500	5,900	30,000	51,200	3,200	7,000
Women	(1)	500	(1)	300	600	1,000	(1)	300
Other engineers	100,700	118,900	7,900	10,900	80,700	130,600	18,000	37,600
Men	100,100	115,200	7,900	9,900	79,700	123,600	17,600	32,300
Women	600	3,600	(1)	1,000	900	6,900	400	5,300

[1] Too few cases to estimate.

Note: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview* (NSF 85-302).
See figures 3-5, 3-9, 3-11, 3-16, and 3-22

Appendix table 3-10. Employed doctoral scientists and engineers, by field, sex, and primary work activity: 1973 and 1983

Field and sex	Total		Research		Development		Management of R&D		Management—other than R&D		Teaching	
	1973	1983	1973	1983	1973	1983	1973	1983	1973	1983	1973	1983
Total, all S E fields	220,300	369,300	63,000	104,500	8,500	20,300	26,200	31,400	13,200	30,400	79,900	108,200
Men	203,400	320,500	58,500	91,100	8,400	19,000	25,500	30,000	12,500	26,500	72,500	92,700
Women	16,900	48,800	4,500	13,400	200	1,200	700	1,400	800	3,800	7,500	15,500
Total scientists	184,600	307,800	54,700	89,500	3,500	10,500	19,300	20,900	11,000	25,400	71,100	96,400
Men	167,800	260,000	50,200	76,500	3,400	9,500	18,600	19,600	10,200	21,600	63,600	81,000
Women	16,800	47,800	4,500	13,100	100	1,000	700	1,300	800	3,800	7,400	15,400
Physical scientists	48,500	64,000	18,000	25,600	1,900	3,500	7,700	8,800	2,200	3,100	14,300	14,700
Men	46,600	59,800	17,400	23,800	1,900	3,300	7,600	8,500	2,100	2,900	13,400	13,500
Women	1,900	4,200	600	1,700	(1)	200	100	300	100	200	900	1,200
Mathematical scientists	12,100	16,400	2,500	2,900	200	500	400	500	500	1,000	8,000	9,700
Men	11,400	15,000	2,400	2,700	100	400	300	500	400	900	7,400	8,800
Women	800	1,400	100	200	(1)	100	(1)	(1)	(1)	100	600	900
Computer specialists	2,700	12,200	500	1,500	600	3,900	300	1,100	200	900	900	2,400
Men	2,600	10,900	500	1,400	500	3,500	300	1,000	200	800	900	2,200
Women	100	1,300	(1)	100	(1)	300	(1)	100	(1)	100	(1)	200
Environmental scientists	10,300	16,500	3,500	6,400	100	300	1,400	1,800	600	1,300	3,100	3,400
Men	10,100	15,600	3,400	6,000	100	300	1,400	1,800	600	1,300	3,000	3,300
Women	300	900	100	400	(1)	(1)	(1)	100	(1)	100	100	200
Life scientists	56,700	92,800	22,800	39,500	400	1,500	6,600	6,200	2,600	6,800	17,800	22,500
Men	50,600	76,600	20,000	32,100	400	1,300	6,300	5,800	2,400	5,700	15,600	18,000
Women	6,100	16,200	2,800	7,400	(1)	200	300	400	200	1,100	2,200	4,500
Psychologists	24,800	46,600	3,200	4,700	200	300	1,500	900	2,500	4,700	9,300	12,700
Men	20,000	33,000	2,700	3,400	100	200	1,400	800	2,200	3,600	7,500	9,300
Women	4,800	13,700	500	1,300	(1)	100	100	100	400	1,100	1,800	3,500
Social scientists	29,400	59,300	4,200	8,900	200	500	1,400	1,600	2,500	7,700	17,700	31,100
Men	26,500	49,300	3,800	7,000	100	400	1,300	1,300	2,400	6,500	15,800	26,100
Women	2,900	10,100	400	1,900	(1)	100	100	300	100	1,200	1,900	5,000

(continued)

Table 3-10. (Continued)

Field and sex	Total		Research		Development		Management of R&D		Management—other than R&D		Teaching	
	1973	1983	1973	1983	1973	1983	1973	1983	1973	1983	1973	1983
Total engineers	35,800	61,500	8,300	15,000	5,000	9,800	7,000	10,500	2,200	5,000	8,900	11,800
Men	35,600	60,500	8,200	14,600	4,900	9,500	6,900	10,400	2,200	4,900	8,800	11,700
Women	100	1,100	(1)	300	(1)	300	(1)	100	(1)	(1)	(1)	200
Aeronautical astronautical	1,700	3,700	400	1,000	100	800	600	600	100	200	300	500
Men	1,700	3,600	400	1,000	100	800	600	800	100	200	300	500
Women	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Chemical	4,500	7,000	900	2,100	800	900	900	1,100	400	600	700	1,100
Men	4,500	6,900	900	2,000	800	900	900	1,100	400	600	700	1,100
Women	(1)	100	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Civil	3,100	5,300	400	600	200	300	300	200	300	600	1,300	2,100
Men	3,100	5,200	400	600	200	300	300	200	300	600	1,300	2,100
Women	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Electrical electronics	7,100	12,700	1,400	2,500	1,400	2,600	1,400	2,800	300	1,100	2,000	2,400
Men	7,000	12,500	1,400	2,400	1,400	2,500	1,300	2,800	300	1,100	2,000	2,400
Women	(1)	200	(1)	100	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)
Materials	4,500	7,400	1,500	2,900	400	600	1,200	1,900	100	400	700	800
Men	4,400	7,300	1,500	2,900	400	600	1,200	1,900	100	400	700	800
Women	(1)	200	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Mechanical	3,300	5,700	600	800	500	1,100	400	600	200	500	1,300	1,900
Men	3,300	5,600	600	800	500	1,000	400	600	200	500	1,300	1,800
Women	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Nuclear	1,300	2,300	200	600	200	500	300	300	100	300	200	300
Men	1,300	2,300	200	600	200	500	300	300	100	300	200	300
Women	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Systems design	2,000	3,900	400	500	300	1,400	300	700	100	100	400	600
Men	1,900	3,800	400	400	300	1,300	300	700	100	100	400	600
Women	(1)	100	(1)	(1)	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)
Other engineers	8,600	13,600	2,400	4,100	1,000	1,600	1,700	2,100	600	1,200	1,900	2,100
Men	8,500	13,300	2,400	4,000	1,000	1,500	1,700	2,100	600	1,200	1,900	2,100
Women	(1)	300	(1)	100	(1)	100	(1)	(1)	(1)	(1)	(1)	(1)

[1] Too few cases to estimate

Note: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States*, biennial series, and unpublished data.

See figure 3-16

Appendix table 3-11. Selected employment characteristics of scientists and engineers, by field: 1983

Field	Labor force participation rate	Unemploy-ment rate	S/E Employment rate	S/E Under-employment rate	S/E Under-utilization rate
Total, all S/E fields	94.9	2.2	88.0	1.9	4.1
Total scientists	95.1	2.6	81.5	3.6	6.1
Physical scientists	93.5	2.5	92.6	1.1	3.5
Chemists	92.7	2.7	92.2	1.0	3.6
Physicists/astronomers	94.9	1.9	94.3	1.4	3.3
Other physical scientists	95.7	2.4	92.0	1.2	3.5
Mathematical scientists	94.0'	2.1	86.3	2.1	4.2
Mathematicians	93.7	2.2	84.6	2.2	4.3
Statisticians	95.0	1.9	91.6	1.8	3.7
Computer specialists	97.7	1.1	72.3	2.3	3.4
Environmental scientists	94.1	2.8	94.9	1.7	4.5
Earth scientists	94.2	2.7	94.9	1.8	4.5
Oceanographers	97.3	3.7	90.6	.2	8.9
Atmospheric scientists	92.9	1.7	95.8	1.4	3.0
Life scientists	94.5	2.5	88.4	3.8	6.2
Biological scientists	94.4	2.5	89.8	4.2	6.7
Agricultural scientists	94.5	2.9	84.4	3.7	6.5
Medical scientists	95.6	1.0	87.0	.4	1.4
Psychologists	95.6	3.2	76.2	6.2	9.1
Social scientists	94.5	4.9	70.1	7.0	11.5
Economists	94.6	4.2	72.8	4.0	8.1
Sociologists/anthropologists	95.1	4.7	65.8	12.5	16.6
Other social scientists	93.9	6.0	69.5	7.0	12.6
Total engineers	94.8	1.9	93.1	.6	2.5
Aeronautical/astronautical	94.5	1.8	95.5	.4	2.2
Chemical	92.9	2.9	93.3	.9	3.8
Civil	94.9	1.9	94.4	.7	2.6
Electrical/electronics	95.9	1.2	94.5	.4	1.7
Industrial	94.2	2.5	88.8	1.1	3.5
Materials	93.5	2.6	92.2	.7	3.2
Mechanical	94.0	2.1	93.4	.5	2.5
Mining	92.5	2.7	88.3	1.4	4.1
Nuclear	97.4'	2.4	96.9	.3	2.8
Petroleum	96.5	1.3	90.5	.0	1.4
Other engineers	95.0	2.0	91.1	.6	2.6

Note: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview* (NSF 85-302).

See figures 3-12, 3-24, and 3-25.

Appendix table 3-12. Average annual salaries of scientists and engineers, by field and sex/race/ethnic group: 1982

Field	Total	Men	Women	White	Black	Asian	Native American	Hispanic
Total, all S/E fields	$33,900	$34,900	$26,300	$34,100	$29,800	$34,100	$34,000	$31,300
Total scientists	31,600	33,200	25,800	31,700	28,400	32,300	32,300	27,300
Physical scientists	34,500	35,300	26,100	34,700	29,600	32,500	42,500	32,700
Chemists	33,400	34,400	25,200	33,700	28,900	30,400	42,300	28,600
Physicists astronomers	37,700	38,000	32,400	37,700	34,600	40,500	43,500	40,500
Other physical scientists	34,700	35,500	26,200	34,600	33,000	37,100	42,100	39,800
Mathematical scientists	34,700	37,400	29,000	34,900	31,000	34,300	31,200	25,400
Mathematicians	35,200	37,600	29,400	35,500	31,000	35,800	31,200	30,000
Statisticians	32,700	36,600	28,100	33,000	30,900	28,600	(1)	17,200
Computer specialists	32,200	33,400	28,700	32,300	31,200	32,000	33,000	30,600
Environmental scientists	36,600	37,900	29,500	36,500	30,700	37,200	46,600	38,500
Earth scientists	37,400	38,800	30,000	37,300	31,200	38,100	42,200	39,800
Oceanographers	34,500	36,400	22,500	33,300	28,200	30,000	56,400	22,400
Atmospheric scientists	32,600	33,000	28,200	32,600	29,400	33,600	(1)	31,400
Life scientists	28,800	30,300	22,400	28,900	27,700	28,000	30,800	25,400
Biological scientists	23,100	29,500	22,500	28,200	28,000	27,300	25,800	24,100
Agricultural scientists	27,400	28,800	17,900	27,400	26,200	28,000	35,700	27,000
Medical scientists	38,700	42,400	28,000	39,100	27,100	31,900	34,500	30,700
Psychologists	28,700	31,600	23,900	28,900	25,900	28,400	23,300	20,400
Social scientists	30,500	32,800	24,300	30,600	26,400	34,300	29,000	23,900
Economists	34,600	35,700	29,600	34,600	31,100	37,200	23,700	30,200
Sociologists anthropologists	24,800	26,900	21,500	24,800	23,800	26,700	28,500	18,100
Other social scientists	29,000	31,900	22,600	29,300	26,700	29,000	32,000	25,700
Total engineers	35,700	36,000	29,000	35,900	31,700	35,000	35,000	33,700
Aeronautical astronautical	38,500	38,800	27,700	38,700	33,400	36,900	28,300	34,000
Chemical	39,200	39,700	31,000	39,700	30,900	35,400	27,800	33,900
Civil	33,400	33,600	26,000	33,600	30,700	33,700	35,500	30,600
Electrical electronics	36,300	36,500	29,700	36,500	33,100	36,000	35,700	35,600
Industrial	32,700	33,000	26,700	32,900	27,700	31,200	33,200	32,100
Materials	36,800	37,200	28,600	37,200	32,000	32,400	39,700	31,600
Mechanical	36,200	36,400	29,300	36,300	32,300	35,300	37,800	35,800
Mining	37,600	38,000	24,900	37,800	25,500	33,600	28,000	27,800
Nuclear	38,400	38,600	30,100	38,600	36,100	34,600	(1)	31,800
Petroleum	44,500	45,100	35,300	44,800	34,600	46,300	32,800	40,800
Other engineers	34,600	34,900	29,100	34,700	31,000	35,100	33,600	32,900

[1] Too few cases to estimate.

Note: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview* (NSF 85-302).

See figures 3-14 and 3-26

Appendix table 3-13. Average monthly salary offers to bachelor's degree candidates, in selected fields: 1976/1977 - 1982/1983

Curriculum	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83
Business	$ 927	$ 993	$1,102	$1,218	$1,356	$1,477	$1,486
Humanities	810	871	983	1,074	1,204	1,283	1,380
Social sciences	863	930	1,020	1,131	1,246	1,391	1,432
Engineering:							
Chemical	1,389	1,513	1,642	1,801	2,030	2,256	2,228
Civil	1,185	1,288	1,402	1,554	1,775	1,925	1,869
Electrical	1,245	1,367	1,520	1,690	1,882	2,064	2,128
Mechanical	1,286	1,404	1,536	1,703	1,908	2,098	2,096
Petroleum	1,512	1,653	1,793	1,987	2,221	2,539	2,568
Agricultural sciences	924	965	1,046	1,192	1,287	1,391	1,375
Biological sciences	882	1,036	1,017	1,159	1,268	1,375	1,419
Chemistry	1,102	1,191	1,332	1,459	1,637	1,751	1,712
Computer sciences	1,123	1,266	1,401	1,558	1,726	1,908	1,941
Mathematics	1,073	1,185	1,324	1,475	1,624	1,777	1,799

SOURCE: CPC Salary Survey, *Formal Report* (Bethlehem, Pa.: College Placement Council), annual series.

Science Indicators—1985

Appendix table 3-14. Percent of scientists and engineers employed involuntarily in non-S/E jobs, by field: 1982

Field	Percent
All scientists and engineers	9.7
Total scientists	12.2
Physical scientists	5.2
Mathematical scientists	16.6
Computer specialists	6.9
Environmental scientists	13.1
Life scientists	19.6
Psychologists	16.3
Social scientists	15.2
Total engineers	4.1
Aeronautical/astronautical	5.9
Chemical	8.6
Civil	6.0
Electrical/electronics	3.4
Industrial	4.5
Materials	3.6
Mechanical	3.2
Mining	3.6
Nuclear	0.8
Petroleum	0.8
Other engineers	3.4

Note: Involuntary non-S/E employment is defined as the percent of those S/Es employed in non-S/E who believe a job in S/E is not available.

SOURCE: National Science Foundation, unpublished data.

See figures 3-13 and 3-20.

Science Indicators—1985

Appendix table 3-15. Doctoral intensity of the science and engineering work force, by field: 1983

Field	Percent
All scientists and engineers	10.7
Total scientists	20.2
Physical scientists	27.1
Mathematical scientists	18.9
Computer specialists	3.5
Environmental scientists	17.4
Life scientists	25.2
Psychologists	32.5
Social scientists	24.0
Total engineers	3.2
Aeronautical astronautical	4.4
Chemical	6.1
Civil	1.9
Electrical electronics	2.7
Materials	18.2
Mechanical	1.5
Nuclear	12.2
Other engineers	4.3

Note: Doctoral intensity is defined as employed doctoral scientists and engineers as a percent of all employed scientists and engineers.

SOURCE: National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States: 1983* (NSF 85-303).

See figure 3-15.

Appendix table 4-1. Scientists and engineers in business and industry, by primary work activity and field: 1976

		Research and development[1]							
	Total Industry	Total	Basic research	Applied research	Development	Management of R&D	Other management	Production inspection	Other industry[2]
All fields	1,456,500	451,700	8,500	77,000	366,100	154,800	324,100	182,800	343,200
All scientists	430,300	104,200	5,900	48,200	50,200	50,600	101,800	38,900	134,900
Physical scientists	105,400	45,500	4,400	21,300	19,800	22,200	15,900	12,000	9,700
Mathematical scientists	14,900	2,600	100	1,400	1,100	3,100	5,800	1,200	2,300
Computer specialists	86,800	22,300	100	800	21,400	6,100	10,200	2,900	45,200
Environmental scientists	30,900	12,600	400	9,400	2,800	4,300	6,000	2,000	6,000
Life scientists	71,500	16,700	800	12,000	4,000	8,100	19,600	8,600	18,600
Psychologists	26,400	1,900	(3)	1,200	700	2,100	7,600	200	14,600
Social scientists	94,400	2,600	100	2,100	400	4,700	36,700	12,000	38,500
All engineers	1,026,200	347,500	2,700	28,800	315,900	104,200	222,200	143,900	208,400
Aeronautical engineers	40,300	18,900	400	2,300	16,200	11,000	3,500	2,600	4,300
Chemical engineers	69,200	25,500	100	3,100	22,200	6,500	19,600	9,000	8,700
Civil engineers	88,800	18,100	100	1,000	17,000	2,800	28,600	15,700	23,700
Electrical engineers	223,500	93,800	800	6,800	86,300	32,100	38,900	24,000	34,700
Industrial engineers	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
Mechanical engineers	230,400	98,100	400	4,900	92,800	25,800	49,100	26,300	31,100
Other engineers	374,000	93,100	900	10,800	81,500	26,000	82,500	66,400	106,000

[1] Excludes R&D management.

[2] Includes consulting, teaching, sales professional services, reporting, statistical work, computing, other, and no report.

[3] Too few cases to estimate.

[4] Data not separately classified; included in other engineers.

Note: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview* (NSF 85-302), p. 131 and unpublished data.

See figure 4-1.

Science Indicators—1985

Appendix table 4-2. Scientists and engineers in business and industry, by primary work activity and field: 1983

		Research and development[1]							
	Total Industry	Total	Basic Research	Applied Research	Development	Management of R&D	Other management	Production inspection	Other industry[2]
All fields	2,330,200	764,600	16,100	117,100	631,400	211,500	432,200	343,100	578,800
All scientists	782,100	192,600	11,100	74,200	107,200	72,500	146,100	70,200	300,700
Physical scientists	140,900	69,000	5,900	30,300	32,800	22,800	19,200	18,600	11,300
Mathematical scientists	28,700	5,000	100	2,200	2,700	5,500	8,600	1,700	7,900
Computer specialists	276,500	55,000	400	4,700	49,900	16,600	21,900	8,200	174,700
Environmental scientists	59,100	25,000	1,300	14,800	8,900	5,500	9,400	6,600	12,600
Life scientists	121,700	27,900	2,800	15,900	9,300	12,200	32,200	23,000	26,500
Psychologists	47,000	2,300	100	1,100	1,000	2,600	13,300	3,700	25,200
Social scientists	108,300	8,500	700	5,200	2,600	7,300	41,500	8,500	42,700
All engineers	1,548,100	572,000	5,000	42,900	524,200	139,000	286,100	272,800	278,100
Aeronautical engineers	62,800	31,800	400	3,600	27,800	11,800	6,300	6,100	6,700
Chemical engineers	103,600	43,200	300	3,900	39,100	9,500	21,600	19,300	9,900
Civil engineers	165,500	32,400	400	1,700	30,300	6,200	44,800	30,200	51,900
Electrical engineers	380,500	175,600	1,300	11,700	162,600	47,600	52,300	58,400	46,600
Industrial engineers	103,600	23,800	100	800	22,900	4,500	29,200	29,100	16,800
Mechanical engineers	322,500	150,800	800	8,000	142,100	30,200	62,200	46,000	33,200
Other engineers	409,600	114,400	1,700	13,200	99,400	29,200	69,700	83,700	113,000

[1] Excludes R&D management.

[2] Includes consulting, teaching, sales professional services, reporting, statistical work, computing, other, and no report.

Note: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview* (NSF 85-302), p. 131 and unpublished data.

See figure 4-1.

Science Indicators—1985

Appendix table 4-3. Recent science and engineering degree recipients employed in business and industry by degree level and field, for selected years

	Bachelor's degree recipients				Master's degree recipients				Doctorate recipients			
	1974 & 1975 in 1976		1980 & 1981 in 1982		1974 & 1975 in 1976		1980 & 1981 in 1982		1977 & 1978 in 1979		1981 & 1982 in 1983	
	Total employed	In business & industry	Total employed	In business & industry	Total employed	In business & industry	Total employed	In business & industry	Total employed	in business & industry	Total employed	in business & industry
All fields	407,000	224,500	391,400	255,100	81,300	30,600	65,200	37,300	32,000	7,000	34,600	9,200
All scientists	323,700	158,400	282,500	168,000	53,800	12,800	44,100	21,100	27,900	4,100	29,700	6,600
Physical scientists	17,400	10,200	16,200	10,400	6,400	2,500	3,500	2,200	4,500	2,000	4,500	2,000
Mathematical scientists	29,500	17,100	18,400	12,700	5,700	1,600	5,200	2,500	1,200	100	1,200	100
Computer specialists	9,000	6,400	23,000	19,200	4,100	2,500	7,700	6,000	1,000	600	1,200	700
Environmental scientists	4,600	2,100	8,300	5,500	1,400	700	2,200	1,500	1,500	400	1,400	500
Life scientists	80,500	39,100	69,400	37,400	13,400	2,900	10,900	3,800	8,200	800	9,500	1,200
Psychologists	64,100	27,200	48,700	22,400	9,200	1,000	5,100	1,600	5,300	400	6,000	1,300
Social scientists	118,800	56,300	98,500	60,400	13,600	1,700	9,500	3,500	6,400	300	6,000	800
All engineers	83,200	66,100	109,000	87,300	27,500	17,700	21,100	16,100	4,100	2,300	4,900	2,600
Aeronautical engineers	NA	NA	1,800	1,100	NA	NA	500	200	NA	NA	300	100
Chemical engineers	NA	NA	10,700	9,800	NA	NA	2,000	1,800	NA	NA	800	300
Civil engineers	NA	NA	18,500	11,900	NA	NA	3,100	2,000	NA	NA	600	200
Electrical engineers	NA	NA	29,500	24,500	NA	NA	5,500	4,600	NA	NA	800	600
Industrial engineers	NA	NA	5,300	4,300	NA	NA	1,300	1,000	NA	NA	0	0
Mechanical engineers	NA	NA	24,400	20,900	NA	NA	3,200	2,600	NA	NA	300	100
Other engineers	NA	NA	18,800	14,800	NA	NA	5,500	3,900	NA	NA	2,100	1,300

Note: NA = Not available.

Note: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Characteristics of Recent Science Engineering Graduates: 1982* (NSF 84-318), pp.15, 34, 53, 72, and unpublished data.

See figure 4-2.

Appendix table 4-4. Expenditures for industrial R&D, by source of funds: 1960-85

Year	Current dollars			Constant 1972 dollars[1]		
	Total	Company[2]	Federal Government[3]	Total	Company[2]	Federal Government[3]
	Million dollars					
1960	$10,509	$ 4,428	$ 6,081	$15,297	$ 6,445	$ 8,852
1961	10,908	4,668	6,240	15,733	6,733	9,000
1962	11,464	5,029	6,435	16,236	7,122	9,113
1963	12,630	5,360	7,270	17,622	7,479	10,144
1964	13,512	5,792	7,720	18,568	7,959	10,609
1965	14,185	6,445	7,740	19,076	8,667	10,409
1966	15,548	7,216	8,332	20,255	9,401	10,855
1967	16,385	8,020	8,365	20,725	10,144	10,581
1968	17,429	8,869	8,560	21,116	10,745	10,371
1969	18,308	9,857	8,451	21,095	11,357	9,737
1970	18,067	10,288	7,779	19,756	11,250	8,506
1971	18,320	10,654	7,666	19,081	11,097	7,985
1972	19,552	11,535	8,017	19,552	11,535	8,017
1973	21,249	13,104	8,145	20,094	12,391	7,702
1974	22,887	14,667	8,220	19,888	12,745	7,143
1975	24,187	15,582	8,605	19,228	12,387	6,981
1976	26,997	17,436	9,561	20,400	13,175	7,225
1977	29,825	19,340	10,485	21,296	13,809	7,487
1978	33,304	22,115	11,189	22,141	14,702	7,439
1979	38,226	25,708	12,518	23,391	15,731	7,660
1980	44,505	30,476	14,029	24,944	17,081	7,863
1981	51,810	35,428	16,382	26,488	18,112	8,375
1982	57,995	39,512	18,483	27,966	19,053	8,913
1983 (Prel.)	62,816	42,601	20,215	29,171	19,783	9,387
1984 (Est.)	69,250	47,250	22,000	31,001	21,147	9,846
1985 (Est.)	77,500	52,400	25,100	33,418	22,588	10,820

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

[2] Includes all sources other than the Federal Government

[3] Data include federally funded R&D centers administered by industry.

Note: Detail may not add to totals because of rounding.

SOURCES: 1960-64: *National Patterns of Science and Technology Resources, 1981* (NSF 81-311), p.21; 1965-84: National Science Foundation, *National Patterns of Science and Technology Resources, 1984* (NSF 84-311), p.28; 1985: National Science Foundation, unpublished tabulations.

See figure 4-3.

Appendix table 4-5. Expenditures for industrial R&D, by industry: 1960-1983

Industry	1960	1962	1964	1966	1968	1970	1972	1974
	Million current dollars							
Total	$10,509	$11,464	$13,512	$15,548	$17,429	$18,067	$19,552	$22,887
All high-technology manufacturing industries	8,304	9,079	10,680	12,244	13,583	13,685	14,558	16,799
Chemicals and allied products	980	1,175	1,284	1,407	1,589	1,773	1,932	2,450
Nonelectrical machinery	949	914	1,015	1,217	1,483	1,729	2,158	2,985
Electrical equipment	2,532	2,639	2,972	3,626	4,083	4,220	4,680	5,011
Aircraft and missiles	3,514	4,042	5,078	5,526	5,765	5,219	4,950	5,278
Professional and scientific instruments	329	309	331	468	663	744	838	1,075
All other manufacturing industries	2,038	2,152	2,515	2,807	3,242	3,677	4,287	5,320
Food and kindred products	104	121	144	164	184	230	259	298
Textiles and apparel	38	28	32	51	58	58	61	69
Lumber, wood products, and furniture	10	10	12	12	20	52	64	84
Paper and allied products	56	65	77	117	144	178	189	237
Petroleum refining and extraction	296	310	393	371	437	515	468	622
Rubber products	121	141	158	168	223	276	377	469
Stone, clay, and glass products	88	96	109	117	142	167	183	217
Primary metals	177	171	195	232	251	275	277	358
Fabricated metal products	145	146	148	154	183	207	253	313
Motor vehicles and other transportation equipment	884	999	1,182	1,344	1,499	1,591	2,010	2,476
Other manufacturing industries	119	65	65	77	101	128	146	177
Nonmanufacturing industries	168	234	319	497	603	705	707	768
	Million constant 1972 dollars							
Total	$15,297	$16,236	$18,568	$20,255	$21,116	$19,756	$19,552	$19,888
All high-technology manufacturing industries	12,087	12,858	14,676	15,951	16,456	14,964	14,558	14,598
Chemicals and allied products	1,426	1,664	1,764	1,833	1,925	1,939	1,932	2,129
Nonelectrical machinery	1,381	1,294	1,395	1,585	1,797	1,891	2,158	2,594
Electrical equipment	3,686	3,737	4,084	4,724	4,947	4,615	4,680	4,354
Aircraft and missiles	5,115	5,724	6,978	7,199	6,984	5,707	4,950	4,586
Professional and scientific instruments	479	438	455	610	803	814	838	934
All other manufacturing industries	2,967	3,048	3,456	3,657	3,928	4,021	4,287	4,623
Food and kindred products	151	171	198	214	223	252	259	259
Textiles and apparel	55	40	44	66	70	63	61	60
Lumber, wood products, and furniture	15	14	16	16	24	57	64	73
Paper and allied products	82	92	106	152	174	195	189	206
Petroleum refining and extraction	431	439	540	483	529	563	468	540
Rubber products	176	200	217	219	270	302	377	408
Stone, clay, and glass products	128	136	150	152	172	183	183	189
Primary metals	258	242	268	302	304	301	277	311
Fabricated metal products	211	207	203	201	222	226	253	272
Motor vehicles and other transportation equipment	1,287	1,415	1,624	1,751	1,816	1,740	2,010	2,152
Other manufacturing industries	173	92	89	100	122	140	146	154
Nonmanufacturing industries	245	331	438	647	731	771	707	667

(Continued)

Appendix table 4-5. (Continued)

Industry	1976	1978	1979	1980	1981	1982	1983
	Million current dollars						
Total	$26,997	$33,304	$38,226	$44,505	$51,810	$57,995	$62,816
All high technology manufacturing industries	19,810	23,904	27,233	31,939	38,354	43,813	47,448
Chemicals and allied products	3,017	3,580	4,038	4,636	5,625	6,659	7,287
Nonelectrical machinery	3,487	4,283	4,825	5,901	6,818	7,835	8,382
Electrical equipment	5,636	6,507	7,824	9,175	10,329	11,642	13,651
Aircraft and missiles	6,339	7,536	8,041	9,198	11,968	13,658	13,741
Professional and scientific instruments	1,331	1,998	2,505	3,029	3,614	4,019	4,387
All other manufacturing industries	6,342	8,171	9,453	10,751	11,550	12,177	13,303
Food and kindred products	355	472	528	620	719	780[1]	876[1]
Textiles and apparel	82	89	101	115	124	130[1]	144[1]
Lumber, wood products, and furniture	107	126	139	148	161	162	171
Paper and allied products	313	387	445	495	570	626	747
Petroleum refining and extraction	767	1,060	1,262	1,552	1,700	2,100[1]	2,229[1]
Rubber products	502	493	577	656	800	850[1]	818[1]
Stone, clay, and glass products	263	324	356	406	470	500[1]	491[1]
Primary metals	506	560	634	728	878	1,000	1,096
Fabricated metal products	358	384	455	550	624	568	634
Motor vehicles and other transpoetation equipment	2,872	4,010	4,668	5,117	5,087	5,090	5,490
Other manufacturing industries	217	266	288	364	417	368[1]	610[1]
Non manufacturing industries	845	1,229	1,540	1,815	1,906	2,005	2,065
	Million constant 1972 dollars						
Total	$20,400	$22,141	$23,391	$24,944	$26,488	$27,966	$29,171
All high-technology manufacturing industries	14,969	15,892	16,664	17,901	19,608	21,127	22,034
Chemicals and allied products	2,280	2,380	2,471	2,598	2,876	3,211	3,384
Nonelectrical machinery	2,635	2,847	2,953	3,307	3,486	3,778	3,892
Electrical equipment	4,259	4,326	4,788	5,142	5,281	5,614	6,339
Aircraft and missiles	4,790	5,010	4,920	5,155	6,119	6,586	6,381
Professional and scientific instruments	1,006	1,328	1,533	1,698	1,848	1,938	2,037
All other manufacturing industries	4,792	5,432	5,784	6,026	5,905	5,872	6,178
Food and kindred products	268	314	323	347	368	376[1]	407[1]
Textiles and apparel	62	59	62	64	63	63[1]	67[1]
Lumber, wood products, and furniture	81	84	85	83	82	78	79
Paper and allied products	237	257	272	277	291	302	347[1]
Petroleum refining and extraction	580	705	772	870	869	1,013[1]	1,035[1]
Rubber products	379	328	353	368	409	410[1]	380[1]
Stone, clay, and glass products	199	215	218	228	240	241[1]	228[1]
Primary metals	382	372	388	408	449	482	509
Fabricated metal products	271	255	278	308	319	274	294
Motor vehicles and other transportation equipment	2,170	2,666	2,856	2,868	2,601	2,454	2,549
Other manufacturing industries	164	177	176	204	213	177[1]	283[1]
Nonmanufacturing industries	639	817	942	1,017	974	967	959

[1] Estimated.

[2] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

Note: Detail may not add to totals because of rounding.

SOURCE: 1960-66: National Science Foundation, *Research and Development in Industry, 1971* (NSF 73-305), p.28; 1968: National Science Foundation, unpublished data; 1970-1979: National Science Foundation, *Research and Development in Industry, 1980* (NSF 82-317) p.11; 1980-82: National Science Foundation, *Research and Development in Industry, 1982* (NSF 84-325) p.10; 1982-83: National Science Foundation, unpublished data.

See figure 4-4.

Appendix table 4-6. Total employment of R&D-performing companies, by industry: 1960-1983

Industry	1960	1962	1964	1966	1968	1970	1972	1974	1976	1978	1979	1980	1981	1982	1983
Total	11,634	11,404	11,561	13,383	14,425	14,443	14,090	14,085	14,088	14,897	15,549	17,276	17,210	15,596	15,238
All high-technology manufacturing industries	4,637	4,807	4,843	5,890	6,480	6,623	6,286	6,403	6,000	6,417	6,734	7,260	7,419	6,485	6,433
Chemicals and allied products	862	948	954	1,036	1,145	1,065	1,052	1,101	1,124	1,164	1,224	1,278	1,311	1,281	1,254
Nonelectrical machinery	1,249	1,178	1,140	1,351	1,492	1,528	1,483	1,547	1,470	1,563	1,649	1,847	2,077	1,690	1,529
Electrical equipment	1,382	1,412	1,582	2,135	2,203	2,355	2,319	2,266	1,984	2,180	2,250	2,286	2,240	1,963	2,106
Aircraft and missiles	864	962	898	1,026	1,241	1,164	965	988	927	974	1,039	987	949	940	921
Professional and scientific instruments	280	309	269	342	399	511	467	491	495	536	572	862	842	611	623
All other manufacturing industries	5,762	5,735	5,832	6,446	6,726	7,254	7,258	7,110	7,265	7,566	7,884	8,120	7,762	7,168	6,896
Food and kindred products	737	784	837	774	779	920	987	951	930	921	958	1,332	1,298	1,291	1,228
Textiles and apparel	388	376	382	538	633	606	602	600	633	608	611	715	628	529	536
Lumber, wood products, and furniture	117	99	112	157	201	244	258	254	302	335	336	290	296	279	277
Paper and allied products	361	402	406	448	473	631	652	592	527	523	528	537	522	518	509
Petroleum refining and extraction	526	506	578	617	627	554	530	469	513	526	529	703	716	672	641
Rubber products	267	283	309	341	355	381	368	376	439	439	445	393	383	360	365
Stone, clay, and glass products	NA	330	335	363	392	361	348	345	404	401	420	434	405	356	341
Primary metals	1,036	1,022	1,016	1,124	1,110	1,090	1,049	1,072	1,056	1,097	1,118	1,068	1,018	880	746
Fabricated metal products	407	455	422	476	514	689	687	707	601	643	669	570	551	499	465
Motor vehicles and other transportation equipment	1,146	1,080	1,149	1,264	1,292	1,350	1,308	1,279	1,283	1,434	1,472	1,381	1,232	1,093	1,093
Other manufacturing industries	777	398	286	344	350	428	469	465	577	639	798	697	733	691	695
Nonmanufacturing industries	1,235	862	886	1,048	1,219	566	546	572	824	914	931	1,898	2,028	1,945	1,910

SOURCE: National Science Foundation, *Research and Development in Industry, 1982* (NSF 84-325), p.37; and unpublished data.

See figure 4-4.

Science Indicators—1985

Appendix table 4-7. Net sales of R&D-performing manufacturing companies, by industry: 1962-1983

Industry	1962	1964	1966	1968	1970	1972	1974
	Million dollars						
Total	$263,713	$287,199	$358,122	$418,034	$467,392	$549,643	$720,849
All high-technology manufacturing industries	98,498	106,121	138,581	167,672	193,914	215,145	272,588
Chemicals and allied products	27,488	29,006	34,627	41,314	45,017	52,141	71,760
Nonelectrical machinery	22,546	24,308	32,917	37,251	43,333	50,015	63,613
Electrical equipment	24,974	29,968	41,747	48,549	59,171	67,220	79,677
Aircraft and missiles	18,057	17,506	21,502	30,336	32,750	30,894	39,111
Professional and scientific instruments	5,433	5,333	7,788	10,222	13,643	14,875	18,427
All other manufacturing industries	165,215	181,078	219,542	250,362	273,478	334,495	448,261
Food and kindred products	34,090	35,954	38,622	39,628	47,202	58,789	76,348
Textiles and apparel	6,197	6,752	9,646	12,091	12,809	13,731	15,989
Lumber, wood products, and furniture	1,911	2,482	3,512	5,192	6,250	7,848	9,774
Paper and allied products	8,917	9,715	12,469	14,303	20,052	24,307	30,267
Petroleum refining and extraction	29,812	34,372	42,470	54,321	54,096	62,496	111,151
Rubber products	6,509	7,707	8,967	10,426	11,770	13,851	17,090
Stone, clay, and glass products	6,529	7,004	7,927	9,075	9,079	10,632	12,320
Primary metals	22,264	25,425	31,472	31,202	32,989	38,215	58,038
Fabricated metal products	9,672	9,645	12,034	13,659	17,295	21,294	25,562
Motor vehicles and other transportation equipment	29,042	33,029	41,378	47,653	44,971	64,157	70,676
Other manufacturing industries	10,272	8,993	11,045	12,812	16,965	19,175	21,046
	Million constant 1972 dollars[1]						
Total	$373,478	$394,667	$466,548	$506,462	$511,090	$549,643	$626,389
All high-technology manufacturing industries	139,496	145,831	180,538	203,140	212,044	215,145	236,868
Chemicals and allied products	38,929	39,860	45,111	50,053	49,226	52,141	62,357
Nonelectrical machinery	31,930	33,404	42,883	45,131	47,384	50,015	55,277
Electrical equipment	35,369	41,182	54,386	58,819	64,703	67,220	69,236
Aircraft and missiles	25,573	24,057	28,012	36,753	35,812	30,894	33,986
Professional and scientific instruments	7,694	7,329	10,146	12,384	14,919	14,875	16,012
All other manufacturing industries	233,982	248,836	286,011	303,322	299,046	334,495	389,521
Food and kindred products	48,279	49,408	50,315	48,011	51,615	58,789	66,343
Textiles and apparel	8,776	9,279	12,566	14,649	14,007	13,731	13,894
Lumber, wood products, and furniture	2,706	3,411	4,575	6,290	6,834	7,848	8,493
Paper and allied products	12,629	13,350	16,244	17,329	21,927	24,307	26,301
Petroleum refining and extraction	42,221	47,234	55,328	65,812	59,154	62,496	96,586
Rubber products	9,218	10,591	11,682	12,631	12,870	13,851	14,851
Stone, clay, and glass products	9,247	9,625	10,327	10,995	9,928	10,632	10,706
Primary metals	31,531	34,939	41,001	37,802	36,073	38,215	50,433
Fabricated metal products	13,698	13,254	15,677	16,548	18,912	21,294	22,212
Motor vehicles and other transportation equipment	41,130	45,388	53,906	57,733	49,176	64,157	61,415
Other manufacturing industries	14,548	12,358	14,389	15,522	18,551	19,175	18,288

(Continued)

Appendix table 4-7. (Continued)

Industry	1976	1978	1979	1980	1981	1982	1983
	Million dollars						
Total	$852.209	$1.049.286	$1.214.986	$1.427.559	$1.589.185	$1.479.343	$1.596.535
All high-technology manufacturing industries	309.082	385.036	449.539	493.364	564.416	572.468	605.239
Chemicals and allied products	82.524	100.482	118.094	129.190	155.504	156.402	167,001
Nonelectrical machinery	71,220	88.848	100.897	117.173	137.905	143,237	145,161
Electrical equipment	83,725	104,214	124.761	139.261	151,870	150,344	159,135
Aircraft and missiles	49,993	62.847	72.610	67.302	74,734	77,083	86,713
Professional and scientific instruments	21.620	28.645	33.177	40.438	44.403	45,402	47,229
All other manufacturing industries	543.128	664.250	765.447	934.195	1,024.767	906,876	991,295
Food and kindred products	89,016	100.107	110.103	155,676	174,216	174,073	184,871
Textiles and apparel	20,436	22.445	25,053	29,052	29.506	26.676	28.857
Lumber, wood products, and furniture	14,594	19.372	21.574	18,899	19.240	18,789	20,982
Paper and allied products	32.974	39.949	45,708	49,263	54,511	53,131	59,896
Petroleum refining and extraction	123,991	141.933	188.434	258,980	308.383	264,076	294,991
Rubber products	21,248	26.028	30.069	29,400	31,693	30,994	34,261
Stone, clay, and glass products	21,544	25,777	29.169	28,670	29,845	27,246	31,206
Primary metals	63,237	85,272	104,006	109,034	101,827	88,748	86,731
Fabricated metal products	30.146	36.572	43,084	40,126	45,046	42,941	41,440
Motor vehicles and other transportation equipment	95,429	126,765	124,846	130,030	137,812	119,854	143,933
Other manufacturing industries	30,513	40,030	43,401	85,065	92,688	60,348	64,127
	Million constant 1972 dollars[1]						
Total	$643,954	$697,571	$743,474	$800,112	$812,467	$713,349	$741,402
All high-technology manufacturing industries	233,551	255,974	275,082	276,518	288,556	276,048	281,062
Chemicals and allied products	62,358	66,801	72,264	72,408	79,501	75,418	77,552
Nonelectrical machinery	53,816	59,067	61,741	65,673	70,504	69,070	67,410
Electrical equipment	63,265	69,282	76,344	78,052	77,643	72,497	73,899
Aircraft and missiles	37,776	41,781	44,432	37,721	38,208	37,170	40,268
Professional and scientific instruments	16,337	19,043	20,302	22,664	22,701	21,893	21,932
All other manufacturing industries	410,404	441,597	468,392	523,593	523,910	437,302	460,339
Food and kindred products	67,263	66,552	67,374	87,253	89,067	83,939	85,851
Textiles and apparel	15,442	14,922	15,330	16,283	15,085	12,863	13,401
Lumber, wood products, and furniture	11,028	12,879	13,202	10,592	9,836	9,060	9,744
Paper and allied products	24,916	26,558	27,970	27,611	27,869	25,620	27,815
Petroleum refining and extraction	93,691	94,358	115,307	145,152	157,660	127,339	136,988
Rubber products	16,056	17,304	18,400	16,478	16,203	14,946	15,910
Stone, clay, and glass products	16,279	17,137	17,849	16,069	15,258	13,138	14,492
Primary metals	47,784	56,689	63,643	61,111	52,059	42,795	40,276
Fabricated metal products	22,779	24,313	26,364	22,490	23,030	20,706	19,244
Motor vehicles and other transportation equipment	72,109	84,274	76,396	72,879	70,456	57,794	66,840
Other manufacturing	23,057	26,612	26,558	47,677	47,387	29,100	29,779

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *Research and Development in Industry, 1982* (NSF 84-325), p.22; and unpublished data.

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Appendix table 4-8. U.S. patents granted, by nationality of inventor: 1960-84

Year	By date of application			By date of grant		
	All U.S. patents	To U.S. inventors	To foreign inventors	All U.S. patents	To U.S. inventors	To foreign inventors
1960	NA	NA	NA	47,170	39,472	7,698
1961	NA	NA	NA	48,368	40,154	8,214
1962	NA	NA	NA	55,691	45,579	10,112
1963	NA	NA	NA	45,679	37,174	8,505
1964	NA	NA	NA	47,375	38,411	8,964
1965	54,840	42,205	12,635	62,857	50,332	12,525
1966	59,661	45,004	14,657	68,405	54,634	13,771
1967	60,007	44,153	15,854	65,652	51,274	14,378
1968	62,965	45,334	17,631	59,103	45,783	13,320
1969	65,846	46,388	19,458	67,559	50,395	17,164
1970	65,944	45,852	20,092	64,429	47,077	17,352
1971	66,358	45,584	20,774	78,317	55,984	22,333
1972	63,360	42,434	20,926	74,810	51,524	23,286
1973	66,286	42,738	23,548	74,143	51,504	22,639
1974	66,385	41,835	24,550	76,278	50,650	25,628
1975	65,821	42,208	23,613	72,002	46,717	25,285
1976	65,715	41,576	24,139	70,226	44,280	25,946
1977	65,791	40,721	25,070	65,269	41,485	23,784
1978	65,141	39,350	25,791	66,102	41,254	24,848
1979	64,539	38,241	26,298	48,854[1]	30,081[1]	18,773[1]
1980[2]	67,300	39,600	27,700	61,819	37,356	24,463
1981[2]	68,600	39,800	28,800	65,771	39,223	26,548
1982[2]	70,700	40,400	30,300	57,889	33,896	23,993
1983[2]	66,900	37,900	29,000	56,860	32,871	23,989
1984[2]	71,800	39,500	32,400	67,201	38,364	28,837

[1] Patent counts by date of grant for 1979 are spuriously low because of a lack of funds in the Patent Office for printing and issuing patents.

[2] Data by date of application are estimated.

Note: NA = Not available.

SOURCES: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office (OTAF), *All Technologies Report*, 1985; and OTAF, unpublished data.

See figure 4-6.

Science Indicators—1985

Appendix table 4-9. U.S. patents granted to U.S. inventors, by type of owner: 1961-84

Year	By date of application					By date of grant				
	All patents	U.S. corp.	U.S. gov't	U.S. individual[1]	Foreign[2]	All patents	U.S. corp.	U.S. gov't	U.S. individual[1]	Foreign[2]
1961	NA	NA	NA	NA	NA	40,154	27,383	1,460	11,233	79
1962	NA	NA	NA	NA	NA	45,579	31,377	1,276	12,817	109
1963	NA	NA	NA	NA	NA	37,174	25,722	1,017	10,358	77
1964	NA	NA	NA	NA	NA	38,411	26,808	1,174	10,336	93
1965	42,205	30,155	1,426	10,475	149	50,332	35,698	1,522	13,032	80
1966	45,004	32,887	1,481	10,412	224	54,634	39,891	1,512	13,050	181
1967	44,153	32,040	1,562	10,313	238	51,274	36,745	1,726	12,634	169
1968	45,334	32,980	1,714	10,362	278	45,783	33,351	1,458	10,768	206
1969	46,388	33,664	1,813	10,601	310	50,395	37,073	1,806	11,299	217
1970	45,852	33,104	1,624	10,869	255	47,077	34,978	1,760	10,096	243
1971	45,584	32,627	1,595	11,105	257	55,984	41,025	2,124	12,585	250
1972	42,434	30,551	1,520	10,143	220	51,524	37,960	1,759	11,569	236
1973	42,738	30,539	1,386	10,602	211	51,504	36,852	2,069	12,346	227
1974	44,835	30,134	1,574	9,890	237	50,650	36,118	1,715	12,556	261
1975	42,208	30,309	1,491	10,233	175	46,717	33,432	1,888	11,183	214
1976	41,576	29,087	1,337	10,934	218	44,280	32,175	1,813	10,083	209
1977	40,721	28,433	1,168	10,875	245	41,485	29,566	1,484	10,249	186
1978	39,350	27,515	1,187	10,384	264	41,254	29,421	1,233	10,399	201
1979	38,241	26,793	1,061	10,107	280	30,081	21,146	960	7,806	169
1980[3]	39,600	28,100	1,100	10,000	300	37,356	25,967	1,232	9,940	217
1981[3]	39,800	29,000	1,300	9,300	300	39,223	27,623	1,115	10,243	242
1982[3]	40,400	29,800	1,300	9,000	300	33,896	24,082	1,003	8,539	272
1983[3]	37,900	27,900	1,300	8,400	300	32,871	24,036	1,043	7,562	230
1984[3]	39,500	29,100	1,300	8,800	300	38,364	27,972	1,224	8,888	280

[1] Includes unassigned patents.

[2] Comprises patents assigned to foreign corporations, governments, and individuals.

[3] Data by date of application are estimated.

Note: NA = Not available.

SOURCES: Office of Technology Assessment and Forecast, U.S. Patent and Trademark Office (OTAF), *All Technologies Report*, 1985; and OTAF, unpublished data.

See figure 4-7.

Appendix table 4-10. Initial public offerings of stock in small high-technology companies: 1976-83

Year	Number of issues	Total amount (millions of dollars)
1976	4	11.7
1977	5	11.8
1978	12	10.1
1979	24	33.8
1980	33	130.8
1981	70	282.7
1982	47	182.6
1983	141	1,513.0

Note: Small companies are defined as those with $500,000 or less in net income after taxes. High-technology companies are those whose primary SIC's are listed on appendix table 4-13.

SOURCE: Securities Data Company, New York City, special tabulations.

See figure 4-8.

Science Indicators—1985

Appendix table 4-11. Capital available and disbursed to new ventures: 1970-84

Year	Net new private capital committed to venture capital firms	Total pool of capital under management	Total industry disbursements	Straight equity-acquisition disbursements[1]
	Million dollars			
1970	$97	$2,500[2]	$350	—
1971	95	2,600[2]	410	—
1972	62	2,700[2]	425	—
1973	56	2,700[2]	450	—
1974	57	2,800[2]	350	—
1975	10	2,800[2]	250	$136
1976	50	2,900[2]	300	185
1977	39	2,900[2]	400	207
1978	600	3,500	550	332
1979	300	3,800	1,000	665
1980	700	4,500	1,100	799
1981	1,300	5,800	1,400	1,171
1982	1,800	7,600	1,800	1,566
1983	4,500	12,100	2,800	2,457
1984	4,200	16,300	3,000	2,631

[1] Excludes SBIC straight debt lending and leveraged buyout financing, but includes mixed equity-debt financings.

[2] Estimated.

SOURCE: Venture Economics, *Venture Capital Investment Trends: 1981-1983, Report to the National Science Foundation* (July, 1984), and unpublished data.

Science Indicators—1985

Appendix table 4-12. Venture capital investments[1] in small companies, by technology category: 1975, 1980, and 1983

	1975	1980	1983
	Million dollars		
All early-and later-stage funding	136	799	2,457
High-technology manufacturing	75	427	1,592
Other manufacturing	44	207	88
Nonmanufacturing	18	165	776
All early-stage funding	50	343	892
High-technology manufacturing	35	195	593
Other manufacturing	10	92	29
Nonmanufacturing	5	56	271
All later-stage funding	86	456	1,565
High-technology manufacturing	40	232	999
Other manufacturing	34	115	59
Nonmanufacturing	13	109	505

[1] Includes straight equity-acquisition disbursements only.

SOURCE: Venture Economics, *Venture Capital Investment Trends: 1981-1983, Report to the National Science Foundation* (July 1984), Venture Economics, *Venture Capital Investments and Small High- technology Companies, A Measure of the High-Technology, Small Business Sector* (February, 1982), and Venture Economics, unpublished data.

See figure 4-9.

Science Indicators—1985

Appendix table 4-13. Venture capital investments[1] in small companies, for selected fields: 1975, 1980, and 1983

Field	Percent of all early-stage funding			Percent of all early- and later-stage funding		
	1975	1980	1983	1975	1980	1983
All fields	100.0	100.0	100.0	100.0	100.0	100.0
All high-technology product fields	69.6	56.9	66.5	55.0	53.5	64.8
Aircraft and parts	0.0	0.2	0.0	0.0	0.1	0.0
Ordnance, except guided missiles	0.0	0.0	0.0	0.0	0.0	0.0
Guided missiles and spacecraft	0.0	0.0	0.0	0.0	0.0	0.0
Electrical equipment and apparatus	0.2	0.7	0.0	1.0	0.7	0.2
Communication equipment and electronic components	2.6	13.2	21.0	8.9	14.5	17.7
Engines and turbines	0.0	2.1	0.1	0.9	0.9	0.1
Office, computing, and accounting machines	54.6	28.6	37.2	28.6	26.6	38.4
Professional, scientific, and measuring instruments	5.7	2.1	2.1	3.7	3.6	2.2
Optical and medical instruments, photo equipment, watches	3.3	2.9	1.8	6.0	3.6	3.3
Radio and TV receiving equipment	0.0	0.0	0.0	0.0	0.0	0.0
Drugs and medicines	0.6	7.1	4.0	0.2	3.1	2.8
Plastic materials and synthetics	0.0	0.0	0.0	0.9	0.3	0.0
Industrial chemicals	0.0	0.0	0.1	3.9	0.1	0.0
Agricultural chemicals	2.6	0.0	0.2	0.9	0.0	0.1
All other manufacturing fields	19.8	26.9	3.2	32.0	25.9	3.6
All nonmanufacturing fields	10.6	16.2	30.4	13.0	20.6	31.6
Computer services	0.7	4.6	11.4	0.3	4.4	11.1
Communication services	0.0	0.0	2.5	0.0	0.0	3.3

[1] Includes straight equity-acquisition disbursements only.

SOURCE: Venture Economics, *Venture Capital Investment Trends: 1981-1983, Report to the National Science Foundation* (July 1984), p. 15 and Venture Economics, *Venture Capital Investments and Small High-Technology Companies: A Measure of the High-Technology, Small Business Sector* (February, 1982), table 8.

Science Indicators—1985

Appendix table 4-14. New products first marketed in 1982, by size of firm

Firm size, millions of dollars in net sales	Number of products per million dollars of net sales	Number of products per million dollars of R&D
All firms	.045	1.75
Less than 100	.113	3.76
100-350	.067	2.17
350-1000	.027	1.49
1000-4000	.010	0.66
4000 and more	.007	0.59

Note: Data based on samples of 270 and 267 firms.

SOURCE: John A. Hansen, James I. Stein, and Thomas S. Moore, *Industrial Innovation in the United States: A Survey of Three Hundred Companies* (Boston University, Center for Technology and Policy, August 1984), pp. 105 and 128.

See figure 4-10.

Science Indicators—1985

Appendix table 4-15. Industry's expenditures for R&D in universities and colleges: 1960-85

Year	Current dollars	Constant 1972 dollars[1]
	Million dollars	
1960	$40	$58
1961	40	58
1962	40	57
1963	41	57
1964	40	55
1965	41	55
1966	42	55
1967	48	61
1968	55	67
1969	60	69
1970	61	67
1971	70	73
1972	74	74
1973	84	79
1974	96	83
1975	113	90
1976	123	93
1977	139	99
1978	170	113
1979	193	118
1980	235	132
1981	288	147
1982	326	157
1983 (Prel.)	370	172
1984 (Est.)	425	190
1985 (Est.)	485	209

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCES: National Science Foundation, *National Patterns of Science and Technology Resources, 1982* (NSF 82-319), p.24 and National Science Foundation, unpublished tabulations.

See figure 4-11.

Science Indicators—1985

Appendix table 4-16. Doctoral scientists and engineers in business and industry reporting teaching as a secondary work activity, by field: 1983

Field	Teaching scientists and engineers	Fraction teaching
	Number	Percent
All science and engineering fields	3,791	3.34
All scientists	3,212	4.06
Physical scientists	240	0.83
Mathematical scientists	98	4.83
Computer/information specialists	166	2.43
Environmental scientists	223	4.32
Life scientists	577	3.50
Psychologists	1,578	12.11
Social scientists	330	4.88
All engineers	579	1.67
Aero/Astro engineers	61	3.16
Chemical engineers	2	0.04
Civil engineers	57	3.00
Electrical and electronic engineers	74	0.97
Materials science engineers	43	0.87
Mechanical engineers	2	0.07
Nuclear engineers	27	1.95
System design engineers	94	4.17
Other engineers	219	3.06

SOURCE: National Science Foundation, unpublished data.

See figure 4-12.

Science Indicators—1985

Appendix table 4-17. Flow of doctoral scientists and engineers between academia and industry, by field: from 1981 to 1983

Field	Moving from academia in 1981 to industry in 1983	Moving from industry in 1981 to academia in 1983	Ratio: entering industry to leaving industry
All science and engineering fields	4,807	1,729	2.8
All scientists	4,178	1,129	3.7
Physical scientists	797	316	2.5
Mathematical scientists	114	128	0.9
Computer/information specialists	282	150	1.9
Environmental scientists	181	47	3.9
Life scientists	1,382	197	7.0
Psychologists	764	179	4.3
Social scientists	658	112	5.9
All engineers	629	600	1.0

Note: "Academia" refers to four-year colleges, universities, and medical schools.

SOURCE: National Science Foundation, unpublished data.

See figure 4-13.

Science Indicators—1985

Appendix table 4-18. Index of cooperative research between the industry and university sectors, by field: 1973-82

Field	1973	1977	1980	1981	1982
	Percent of industry articles with university participation				
All fields	13	15	19	22	24
Clinical medicine	21	23	30	30	34
Biomedicine	19	26	32	35	37
Biology	19	28	35	39	46
Chemistry	9	10	13	13	17
Physics	13	15	18	20	21
Earth and space sciences	28	27	31	34	35
Engineering and technology	9	10	13	16	17
Mathematics	29	40	39	43	35
	Industry articles with university participation				
All fields	1,566	1,595	2,017	2,905	3,297
Clinical medicine	329	331	467	636	768
Biomedicine	117	148	175	276	305
Biology	86	113	116	176	246
Chemistry	185	158	215	269	357
Physics	246	290	423	508	575
Earth and space sciences	102	95	119	207	241
Engineering and technology	463	418	459	746	732
Mathematics	38	42	43	89	73
	Industry articles				
All fields	12,180	10,544	10,422	13,462	13,705
Clinical medicine	1,600	1,413	1,533	2,086	2,257
Biomedicine	618	567	548	782	824
Biology	446	407	332	752	533
Chemistry	1,983	1,539	1,708	1,999	2,124
Physics	1,911	1,932	2,302	2,559	2,713
Earth and space sciences	358	348	381	606	691
Engineering and technology	5,130	4,231	3,507	4,770	4,356
Mathematics	134	107	111	208	208

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 4-14.

Appendix table 4-19. Federal funding of industrial R&D, for selected industries: 1980 and 1983

Industry	1980	1983
	Million dollars	
Total	$14,029	$20,215
Lumber, wood products, and furniture	NA	0
Chemicals and allied products	372	448
Industrial chemicals	341	440
Petroleum refining and extraction	151	NA
Primary metals	135	391
Ferrous metals and products	105	NA
Nonferrous metals and products	30	NA
Fabricated metal products	49	66
Nonelectrical machinery	647	1,144
Electrical equipment	3,744	5,081
Radio and TV receiving equipment	210	NA
Communication equipment	1,657	2,367
Electronic components	382	346
Other electrical equipment	1,495	NA
Motor vehicles and motor vehicle equipment	655	566
Aircraft and missiles	6,628	10,300
Professional and scientific instruments	573	640
Scientific and mechanical measuring instruments	350	NA
Optical, surgical, photographic, and other instruments	223	NA
Nonmanufacturing industries	779	1,048

SOURCE: National Science Foundation, *Research and Development in Industry, 1983* (in press).

Science Indicators—1985

Appendix table 5-1. Institutions of higher education and Institutions awarding S/E degrees, by highest degree awarded: 1960-84

Year	Total higher education institutions	Four-year institutions							Two-year institutions
			Granting S/E degrees (highest degree)						
		4-year institutions	Total	Bachelors and first professional	Master's	Doctor's	Not granting S/E degrees		
1960	2,021	1,446	1,056	735	180	141	390		575
1961	2,034	1,441	1,090	748	189	153	351		593
1962	2,050	1,464	1,112	745	212	155	352		586
1963	2,106	1,476	1,125	754	209	162	351		630
1964	2,146	1,509	1,147	757	218	172	362		637
1965	2,189	1,532	1,165	754	233	178	367		657
1966	2,247	1,565	1,178	745	246	187	387		682
1967	2,347	1,592	1,217	752	271	194	375		755
1968	2,392	1,603	1,223	746	281	196	380		789
1969	2,503	1,636	1,254	756	292	206	382		867
1970	2,544	1,654	1,274	762	292	220	380		890
1971	2,573	1,681	1,276	760	287	229	405		892
1972	2,626	1,689	1,362	795	319	248	327		937
1973	2,689	1,772	1,396	815	318	263	376		967
1974	2,744	1,737	1,400	802	327	271	337		1,007
1975	3,012	1,871	1,420	813	340	267	451		1,141
1976	3,026	1,898	NA	NA	NA	NA	NA		1,128
1977	3,046	1,905	NA	NA	NA	NA	NA		1,141
1978	3,095	1,925	1,445	804	359	282	493		1,170
1979	3,134	1,925	NA	NA	NA	NA	NA		1,209
1980	3,152	1,934	NA	NA	NA	NA	NA		1,218
1981	3,231	2,007	1,447	793	361	293	560		1,224
1982	3,253	2,039	1,457	797	365	295	582		1,214
1983	3,280	2,074	NA	NA	NA	NA	NA		1,206
1984	3,284	2,012	NA	NA	NA	NA	NA		1,272

Note: NA = Not available.

SOURCE: National Science Foundation, *Databook* (series), February 1969 and January 1975, and unpublished data; National Center for Education Statistics, *Education Directory, 1983-84* (1984).

See figure 5-1.

Science Indicators—1985

Appendix table 5-2. Science and engineering degrees, by level: 1960-82

Year	Total S/E degrees	Bachelor's	Master's	Doctor's
1960	147,005	120,937	20,012	6,056
1961	150,977	121,660	22,786	6,531
1962	159,864	127,469	25,146	7,249
1963	171,386	135,964	27,367	8,055
1964	192,657	153,361	30,271	9,025
1965	209,023	164,936	33,835	10,252
1966	222,852	173,471	38,083	11,298
1967	242,408	187,849	41,800	12,759
1968	271,727	212,174	45,425	14,128
1969	308,783	244,519	48,425	15,839
1970	331,079	264,122	49,318	17,639
1971	340,266	271,176	50,624	18,466
1972	353,207	281,228	53,567	18,412
1973	368,223	295,391	54,234	18,598
1974	377,102	305,062	54,175	17,865
1975	366,556	294,920	53,852	17,784
1976	364,209	292,174	54,747	17,288
1977	362,211	288,543	56,731	16,937
1978	360,600	288,167	56,237	16,196
1979	359,444	288,625	54,456	16,363
1980	362,857	291,983	54,391	16,483
1981	366,651	294,867	54,811	16,973
1982	376,062	302,118	57,025	16,919

SOURCE: National Science Foundation, *Science and Engineering Degrees, 1950-1982* (NSF 84-307), and unpublished data.

See figure 5-1.

Science Indicator—1985

Appendix table 5-3. Science and engineering degrees, by level and field: 1979-82

Degree level and field	1979	1980	1981	1982
Total S/E fields	359,444	362,857	366,651	376,062
Physical sciences ...	31,931	31,989	32,620	33,188
Engineering	72,430	78,605	84,011	89,037
Mathematics	15,677	15,065	14,470	15,120
Computer sciences ..	12,060	15,100	19,703	25,617
Life sciences	110,207	86,390	82,492	79,563
Social sciences	137,139	135,708	132,995	133,537
Total S/E bachelor's ...	288,625	291,983	294,867	302,118
Physical sciences ...	23,363	23,661	24,175	24,372
Engineering	53,720	59,240	64,068	67,791
Mathematics	11,901	11,473	11,173	11,708
Computer sciences ..	8,769	11,213	15,233	20,431
Life sciences	95,085	71,617	68,086	65,041
Social sciences	115,787	114,779	112,132	112,775
Total S/E master's	54,456	54,391	54,811	57,025
Physical sciences ...	5,464	5,233	5,300	5,526
Engineering	16,193	16,846	17,373	18,594
Mathematics	3,046	2,868	2,569	2,731
Computer sciences ..	3,055	3,647	4,218	4,935
Life sciences	10,719	10,278	9,731	9,824
Social sciences	15,979	15,519	15,260	15,415
Total S/E doctor's	16,363	16,483	16,973	16,919
Physical sciences ...	3,104	3,095	3,145	3,290
Engineering	2,517	2,519	2,570	2,652
Mathematics	730	724	728	681
Computer sciences ..	236	240	252	251
Life sciences	4,403	4,495	4,675	4,698
Social sciences	5,373	5,410	5,603	5,347

SOURCES: National Science Foundation, *Science and Engineering Degrees* (NSF 82-307) and unpublished data.

Science Indicators—1985

Appendix table 5-4. Doctoral recipients, by program quality and science and engineering field[1]: 1973-83

Year	All S/E fields			Engineering			Physical and environmental sciences			Math and computer sciences			Biology sciences			Psychology and social sciences		
	Total	Top 25%[2]	Other[3]	Total	Top 25%[2]	Other[3]	Total	Top 25%[2]	Other[3]	Total	Top 25%[2]	Other[3]	Total	Top 25%[2]	Other[3]	Total	Top 25%[2]	Other[3]
1973	14,757	6,088	8,669	2,093	934	1,159	3,716	1,666	2,050	1,265	588	677	2,234	722	1,512	5,449	2,178	3,271
1974	14,243	5,902	8,341	1,934	883	1,051	3,424	1,544	1,880	1,223	551	672	2,083	695	1,388	5,579	2,229	3,350
1975	14,198	5,882	8,316	1,861	858	1,003	3,353	1,597	1,756	1,121	518	603	2,094	729	1,365	5,761	2,250	3,511
1976	13,832	5,759	8,073	1,756	901	855	3,115	1,433	1,682	1,013	482	531	2,072	750	1,322	5,876	2,223	3,653
1977	13,379	5,480	7,899	1,614	759	855	3,005	1,377	1,628	974	450	524	1,983	738	1,245	5,805	2,164	3,641
1978	12,914	5,285	7,629	1,413	740	673	2,817	1,367	1,450	961	453	508	2,005	690	1,315	5,718	2,035	3,683
1979	13,093	5,441	7,652	1,500	754	746	2,926	1,485	1,441	980	478	502	2,047	729	1,318	5,640	1,995	3,645
1980	12,898	5,172	7,726	1,449	745	704	2,761	1,353	1,408	963	465	498	2,174	750	1,424	5,541	1,859	3,682
1981	13,253	5,372	7,881	1,492	783	709	2,851	1,432	1,419	972	483	489	2,140	726	1,414	5,798	1,898	3,900
1982	13,173	5,352	7,821	1,667	877	790	2,967	1,495	1,472	963	470	493	2,114	736	1,378	5,462	1,774	3,688
1983	13,480	5,422	8,058	1,707	867	840	3,034	1,512	1,522	989	474	515	2,137	757	1,380	5,613	1,812	3,801

[1] See appendix table 5-5 for a list of fields included in this table.
[2] "Top 25%" of the rated departments.
[3] "Other" includes Ph.D. recipients in nonrated departments.

SOURCE: National Science Foundation, unpublished data.

See figure 5-2.

Science Indicators—1985

Appendix table 5-5. Fields and subfields included in the Conference Board Study of science and engineering program quality

- Engineering
  - Chemical
  - Civil
  - Electrical
  - Mechanical

- Mathematics and computer sciences
  - Computer science
  - Mathematics
  - Statistics/biostatistics

- Physical and environmental sciences
  - Chemistry
  - Geoscience
  - Physics

- Biological sciences
  - Biochemistry
  - Botany
  - Cellular/molecular
  - Microbiology
  - Physiology
  - Zoology

- Psychology and social sciences
  - Psychology
  - Anthropology
  - Economics
  - Geography
  - Political science
  - Sociology

SOURCE: Jones L., G. Lindzey, and P. Coggeshall, *An Assessment of Research-Doctorate Programs in the United States*. Five volumes, (Washington, D.C.: National Academy Press, 1982).

Science Indicators—1985

Appendix 5-6. Fulltime engineering and technology enrollments, by level: Fall 1976 and Fall 1983

Year of study	Fall 1976	Fall 1983	Average annual percent change
All levels	294,314	463,510	6.7
Master's	25,516	38,826	6.1
Doctoral	10,963	18,540	7.7
Undergraduates	36,479	57,366	6.6
Freshman	82,250	109,638	4.1
Sophomore	63,003	89,515	5.1
Junior	56,835	91,233	6.9
Senior	51,692	109,036	11.2
Fifth year	4,055	6,722	7.4
(Number of schools)	(289)	(292)	

SOURCE: Engineering Manpower commission, *Engineering and Technology Enrollments* (annual series).

Science Indicators—1985

Appendix table 5-7. Employment status of engineers at colleges and universities, by subfield: 1976, 1981, 1983, and 1985

Employment status	January 1976	January 1981	January 1983	January 1985	Percent change	
					76-83	81-83
Engineering	28,495	34,905	37,737	39,861	32	8
FT	22,924	27,017	28,844	30,078	26	7
PT	5,571	7,888	8,893	9,783	60	13
Aeronautical/astronautical	1,133	1,262	1,327	1,529	17	5
FT	966	1,057	1,089	1,212	13	3
PT	167	205	238	317	43	17
Chemical	1,861	2,283	2,410	2,628	30	6
FT	1,638	1,902	1,951	2,159	19	3
PT	223	381	459	469	106	20
Civil	5,032	5,771	6,421	6,655	28	11
FT	4,015	4,446	4,987	5,084	24	12
PT	1,017	1,335	1,434	1,571	41	7
Electrical	6,932	8,583	9,614	10,799	39	12
FT	5,405	6,518	7,188	7,742	33	10
PT	1,527	2,065	2,426	3,057	59	17
Mechanical	5,302	6,323	6,728	7,221	27	6
FT	4,346	4,932	5,112	5,543	18	4
PT	956	1,391	1,616	1,678	69	16
Other engineering	8,235	10,673	11,237	11,030	36	5
FT	6,554	8,162	8,517	8,338	30	4
PT	1,681	2,511	2,720	2,692	62	8

SOURCE: National Science Foundation, *Academic Science/Engineering: Scientists and Engineers, January 1983* (NSF 84-309), 1984, and unpublished tabulations.

See figure 5-3.

Science Indicators—1985

Appendix table 5-8. Career age of fulltime M.D. and Ph.D. faculty members in U.S. medical schools, by department type: 1972 and 1982

Career age[1] and type of department	1972		1982	
	Number	Percent	Number	Percent
Basic science department:				
Total[2]	5,811	100.0	7,484	100.0
Less than 5 years	1,418	24.4	750	10.0
6-10 years	1,325	22.8	1,275	17.1
11 or more years	3,068	52.8	5,459	72.9
Ph.D's	5,059	100.0	6,850	100.0
Less than 5 years	1,384	27.4	744	10.9
6-10 years	1,215	24.0	1,246	18.1
11 or more years	2,460	48.6	4,864	71.0
M.D.'s	752	100.0	634	100.0
Less than 5 years	34	4.5	6	0.9
6-10 years	110	14.6	33	5.2
11 or more years	608	80.9	595	93.9
Clinical department:				
Total[2]	22,002	100.0	34,223	100.0
Less than 5 years	1,916	8.7	2,331	6.8
6-10 years	4,928	22.4	5,836	17.1
11 or more years	15,758	68.9	26,056	76.1
Ph.D's	3,496	100.0	5,857	100.0
Less than 5 years	1,214	34.7	1,117	19.1
6-10 years	836	23.9	1,311	22.4
11 or more years	1,446	41.3	3,429	58.6
M.D.'s	18,506	100.0	28,366	100.0
Less than 5 years	702	3.8	1,214	4.3
6-10 years	4,092	22.1	4,525	16.0
11 or more years	13,712	74.1	22,627	79.8

[1] Years since doctorate: years since Ph.D. or years since M.D.

[2] Total M.D.'s and Ph.D's employed by department, excludes those few individuals holding M.D./Ph.D or other degrees.

SOURCE: Herman and Singer "Basic Scientists in Clinical Departments," Institute of Medicine, Washington, D.C., 1984.

See figure 5-4.

Science Indicators—1985

Appendix table 5-9. Highest degree first-time, fulltime freshmen hope to attain, by probable major field: 1974 and 1983

Probable major field	1974	1983	Change 1974-1983
		Bachelor's	
All Freshmen	37.2	34.0	−3.2
Science/engineering	24.6	25.5	0.9
Other fields	43.8	38.2	−5.6
Undecided major	45.4	38.9	−6.5
		Master's	
All Freshmen	30.6	35.3	4.7
Science/engineering	29.7	36.8	7.1
Other fields	31.4	34.5	3.1
Undecided major	26.5	34.3	7.8
		Ph.D./Ed.D	
All Freshmen	11.2	11.1	−0.1
Science/engineering	18.6	18.0	−0.6
Other fields	7.1	7.4	−0.3
Undecided major	9.6	9.5	−0.1
		Other[1]	
All Freshmen	21.0	19.6	−1.4
Science/engineering	27.1	19.7	−7.7
Other fields	17.7	19.9	2.2
Undecided major	18.5	17.3	−1.2

[1] "Other" includes "Other professional degree", "less than bachelor" and "other".

SOURCE: Higher Education Research Institute, Cooperative Institutional Research Program, unpublished tabulations, October, 1984

Science Indicators—1985

Appendix table 5-10. Probable major of first-time, fulltime freshmen in four-year colleges and universities whose high school grade point average was A, by field: 1974 and 1983

Probable major field	Fall			
	1974		1983	
	Freshmen	Percent	Freshmen	Percent
"A" students	239,952	100.0	261,118	100.0
Science and engineering	104,956	43.7	110,072	42.2
Physical sciences	11,711	4.9	8,233	3.2
Mathematics	9,348	3.9	5,614	2.1
Computer science	2,455	1.0	13,513	5.2
Environmental science	1,965	0.8	1,057	0.4
Engineering	24,611	10.3	45,310	17.4
Biological science	28,055	11.7	17,251	6.6
Social science	27,023	11.3	19,327	7.4
Other fields	123,054	51.3	136,668	52.3
Arts & humanities	33,993	14.2	23,649	9.1
Business	20,094	8.4	41,129	15.8
Education	19,909	8.3	11,809	4.5
Other fields	49,289	20.5	60,427	23.1
Undecided	11,942	5.0	14,379	5.5

Note: These figures represent weighted national estimates. Detail may not add to total due to differences in weighting procedures at the broad field and subfield level.

SOURCE: Higher Education Research Institute, Cooperative Institutional Research Program, unpublished tabulations, October 1984.

See figure 5-6.

Science Indicators—1985

Appendix table 5-11. Proportion of first-time, fulltime freshman having had three or more years of mathematics and physical science in high school, by major field: Fall 1983

Probable major field	Mathematics	Physical science
	Percent	
All fields	88.4	24.4
Science and engineering	94.4	34.7
Physical sciences	98.5	53.7
Mathematics	98.9	36.2
Computer science	94.2	26.4
Engineering	97.0	43.7
Other fields	89.7	25.9
Other fields	85.3	19.4
Arts & humanities	81.7	16.3
Business	86.8	17.0
Education	75.9	13.6
Other fields	88.0	24.5
Undecided	87.9	20.1

SOURCE: Higher Education Research Institute, Cooperative Institutional Research Program, unpublished tabulations, October 1984.

Science Indicators—1985

Appendix table 5-12. Full-time science and engineering graduate enrollments in doctorate-granting institutions, by field and sex: 1980, 1983, and 1984

Field	1980			1983			1984		
	Total	Men	Women	Total	Men	Women	Total	Men	Women
All S E fields	230,535	154,605	75,930	243,596	162,147	81,449	246,848	163,897	82,951
Engineering	41,939	38,016	3,923	53,475	47,680	5,795	54,751	48,582	6,169
Physical sciences	22,254	18,721	3,533	24,492	19,860	4,632	25,149	20,298	4,851
Environmental sciences	10,265	7,930	2,335	11,466	8,640	2,826	11,283	8,562	2,721
Mathematics[1]	9,368	7,228	2,140	10,312	7,646	2,666	10,591	7,855	2,736
Computer science	5,900	4,668	1,232	9,308	7,089	2,219	10,117	7,759	2,358
Life sciences	67,711	37,331	30,380	65,166	34,531	30,635	66,221	34,861	31,360
Agricultural sciences	9,591	7,299	2,292	9,397	7,028	2,369	9,327	6,896	2,431
Biological sciences	35,817	22,633	13,184	35,187	21,149	14,038	35,980	21,506	14,474
Health sciences	22,303	7,399	14,904	20,582	6,354	14,228	20,914	6,459	14,455
Psychology	21,580	10,618	10,962	21,322	9,598	11,724	21,603	9,344	12,259
Social sciences	51,518	30,093	21,425	48,055	27,103	20,952	47,133	26,636	20,497

[1] Includes mathematics, applied mathematics, and statistics.

SOURCE: National Science Foundation, *Academic Science and Engineering: Graduate Enrollment and Support, Fall, 1983* (NSF 85-300).

See figure 5-9

Science Indicators—1985

Appendix table 5-13. Enrollment of foreign citizens as fulltime science and engineering graduate students in doctorate-granting institutions, by field: 1980-84

Field	1980	1981	1982	1983	1984
All S/E fields	48,671	52,598	55,302	59,898	61,065
Engineering	17,503	19,201	20,812	22,373	22,742
Physical sciences	5,586	6,077	6,292	7,041	7,339
Environmental sciences	1,335	1,465	1,604	1,661	1,527
Mathematics[1]	3,155	3,521	3,721	4,080	4,296
Computer science	1,870	2,205	2,771	3,545	3,999
Life sciences	8,485	9,009	9,310	9,961	10,147
Agricultural sciences	2,159	2,288	2,281	2,374	2,304
Biological sciences	4,346	4,637	4,871	5,333	5,631
Health sciences	1,980	2,084	2,158	2,254	2,212
Psychology	1,054	832	887	906	920
Social sciences	9,683	10,288	9,905	10,331	10,095

[1] Includes statistics.

SOURCE: National Science Foundation, *Academic Science and Engineering: Graduate Enrollment and Support, Fall 1983* (NSF 85-300).

See figure 5-9.

Science Indicators—1985

Appendix table 5-14. Distribution of full time foreign student enrollment in science and engineering graduate programs, by field and program quality rating: 1975, 1979, and 1983

Field/quality rating	1975	1979	1983
All S/E fields[1]	100.0	100.0	100.0
Top 25 percent	39.7	36.3	35.0
Other	60.3	63.7	65.0
All engineering[1]	100.0	100.0	100.0
Top 25 percent	42.8	40.3	37.4
Other	57.2	59.7	62.6
All physical and environmental sciences[1]	100.0	100.0	100.0
Top 25 percent	39.1	35.8	37.5
Other	60.9	64.2	62.5
All biological sciences[1]	100.0	100.0	100.0
Top 25 percent	35.0	34.1	32.9
Other	65.0	65.9	67.1
All mathematics and computer sciences[1]	100.0	100.0	100.0
Top 25 percent	44.1	38.5	31.3
Other	55.9	61.5	68.7
All psychology and social sciences[1]	100.0	100.0	100.0
Top 25 percent	34.7	30.0	31.7
Other	65.3	70.0	68.3

[1] Includes only those fields surveyed by the Conference Board. See appendix table 5-5 for a listing of those fields.

SOURCE: National Science Foundation, unpublished tabulations (1985).

Science Indicators—1985

Appendix table 5-15. Full time science and engineering graduate students in doctorate-granting institutions, by field and type of major support: 1975, 1983, and 1984

Field and type of major support	1975	1983	1984	Average annual Percent change 1975-83
All S E fields	210,321	243,596	246,848	1.8
Fellowships and traineeships	38,812	35,407	35,695	-1.1
Research assistantships	40,136	54,162	57,039	3.7
Teaching assistantships	47,348	57,884	59,180	2.5
Other types of support	15,888	20,547	20,387	3.2
Self-support	68,137	75,596	74,547	1.3
Engineering	37,083	53,475	54,741	4.6
Fellowships and traineeships	4,652	5,576	5,574	2.3
Research assistantships	10,987	15,581	16,231	4.4
Teaching assistantships	5,399	9,893	10,368	7.6
Other types of support	4,005	5,064	5,096	2.9
Self-support	12,040	17,361	17,482	4.6
Physical sciences	21,274	24,492	25,149	1.8
Fellowships and traineeships	2,245	2,288	2,413	0.2
Research assistantships	6,441	9,060	9,517	4.3
Teaching assistantships	10,185	10,898	10,979	0.8
Other types of support	559	652	716	1.9
Self-support	1,844	1,594	1,524	-1.8
Environmental sciences	8,989	11,466	11,283	3.0
Fellowships and traineeships	952	1,147	1,117	2.3
Research assistantships	2,838	3,481	3,506	2.6
Teaching assistantships	2,172	2,752	2,743	3.0
Other types of support	711	799	859	1.5
Self-support	2,316	3,287	3,058	4.4
Mathematical computer sciences	14,125	19,620	20,708	4.1
Fellowships and traineeships	1,321	1,324	1,513	0
Research assistantships	1,375	2,142	2,430	5.5
Teaching assistantships	6,491	8,459	8,971	3.3
Other types of support	1,205	1,262	1,264	0.6
Self-support	3,733	6,433	6,530	6.8
Agricultural sciences	8,512	9,397	9,327	1.2
Fellowships and traineeships	891	759	666	-2.0
Research assistantships	3,710	4,509	4,612	2.4
Teaching assistantships	691	879	837	3.0
Other types of support	788	1,029	998	3.3
Self-support	2,432	2,221	2,214	-1.1
Biological sciences	34,795	35,187	35,980	0.1
Fellowships and traineeships	8,675	7,946	8,149	-1.1
Research assistantships	6,787	9,999	10,876	4.8
Teaching assistantships	8,827	8,960	8,948	0.2
Other types of support	1,869	2,264	2,119	2.4
Self-support	8,637	6,018	5,888	-4.5
Health sciences	16,328	20,582	20,914	2.9
Fellowships and traineeships	6,517	6,034	5,993	-1.0
Research assistantships	825	1,567	1,800	8.0
Teaching assistantships	1,695	2,102	2,229	2.7
Other types of support	1,126	2,112	2,242	7.9
Self-support	6,615	8,767	8,650	3.5
Psychology	19,710	21,322	21,603	1.0
Fellowships and traineeships	4,476	2,546	2,636	-7.1
Research assistantships	2,213	2,659	2,761	2.3
Teaching assistantships	4,095	4,648	4,676	1.6
Other types of support	1,682	2,231	2,431	3.5
Self-support	7,244	9,238	9,099	3.0
Social sciences	49,505	48,055	47,133	-0.4
Fellowships and traineeships	9,083	7,787	7,634	-1.9
Research assistantships	4,960	5,164	5,306	0.5
Teaching assistantships	7,793	9,293	9,429	2.2
Other types of support	3,943	5,134	4,662	3.3
Self-support	28,726	20,677	20,102	-4.1

SOURCE: National Science Foundation, *Academic Science and Engineering: Graduate Enrollment and Support, Fall 1982* (NSF 84-306), p. 109, 110, and 123, and unpublished tabulations.

See Figure 5-11.

Appendix table 5-16. Fulltime science and engineering graduate students in doctorate-granting institutions, by source of support 1975-84

Source of major support	1975	1976	1977	1979	1980	1981	1982	1983	1984	Average annual percent change (1975-83)
Total	210,321	214,089	217,453	223,409	230,535	234,194	236,939	243,596	246,846	1.8
Federal agency	48,249	48,594	50,378	52,871	52,939	50,897	47,206	47,445	47,764	−0.2
NIH	12,214	11,360	10,928	11,660	11,560	11,283	10,860	10,852	11,220	−1.5
NSF	8,796	8,962	9,023	9,275	9,243	9,084	9,207	9,476	9,813	0.9
DOD	5,084	4,798	4,993	4,998	5,239	5,647	5,867	6,901	7,034	3.9
Other agencies	22,155	23,474	25,434	26,938	26,897	24,883	21,278	20,216	19,697	−1.1
Institutional	77,083	79,217	80,404	82,813	86,715	90,261	93,244	96,124	99,978	2.8
Other sources	16,852	17,680	18,229	20,039	21,066	22,382	23,630	24,431	24,559	4.6
Other U.S	11,440	11,373	11,323	12,493	13,063	13,832	14,863	15,733	16,591	4.0
Foreign	5,412	6,307	6,906	7,546	8,003	8,550	8,767	8,698	7,968	5.9
Self-support	68,123	68,598	68,442	67,686	69,815	70,654	72,859	75,596	74,547	1.3

SOURCE: National Science Foundation, *Academic Science and Engineering: Graduate Enrollment and Support, Fall 1982* (NSF 84-306), p.109, and unpublished tabulations.

Science Indicators—1985

Appendix table 5-17. Relative change in science and engineering graduate students[1] with federal support, by field: 1975, 1983 and 1984

Field	1975 Number	1975 Percent of total	1983 Number	1983 Percent of total	1984 Number	1984 Percent of total	Percent change 1975-83
All S/E fields	48,249	100.0	47,445	100.0	47,764	100.0	−1.8
Engineering	10,258	21.2	11,916	25.1	11,500	24.1	16.2
Physical sciences	6,208	12.9	8,050	17.0	8,549	17.9	29.6
Environmental sciences	2,693	5.6	2,845	6.0	2,823	5.9	5.4
Mathematics[2]	693	1.4	747	1.6	755	1.6	8.1
Computer sciences	743	1.5	1,045	2.2	1,217	2.5	40.6
Agricultural sciences	1,637	3.4	1,510	3.2	1,350	2.8	−7.8
Biological sciences	9,951	20.6	10,161	21.4	10,532	22.1	2.3
Health sciences	6,000	12.4	5,556	11.7	5,562	11.6	−7.9
Psychology	4,324	9.0	1,980	4.2	1,942	4.1	−54.2
Social sciences	5,742	11.9	3,635	7.7	3,534	7.4	−37.4

[1] Full-time students in doctorate-granting institutions only.

[2] Includes statistics.

SOURCE: National Science Foundation *Academic Science and Engineering: Graduate Enrollment and Support, Fall 1982* (NSF 84-306), p. 111, and unpublished tabulations.

Science Indicators—1985

Appendix table 5-18. Fulltime science and engineering graduate students with federally-funded fellowships, traineeships and research assistantships, by field, type of support, and program quality rating: 1975-82[1]

Field quality rating	1975	1976	1977	1979	1980	1981	1982	Percent change 1975-1982
	Fellowships traineeship							
S E fields[2]	9,236	8,249	7,882	6,827	6,284	5,510	4,895	-47.0
Top 25 percent	4,913	4,336	4,169	3,662	3,385	2,900	2,683	-45.4
Other	4,323	3,913	373	3,165	2,899	2,610	2,212	-48.8
Engineering[2]	976	848	775	517	512	436	464	-52.4
Top 25 percent	451	414	408	286	302	253	269	-40.4
Other	525	434	367	231	210	183	195	-62.9
Physical environmental science[2]	684	721	791	808	761	666	577	-15.6
Top 25 percent	496	459	464	475	448	369	340	-31.5
Other	188	262	327	333	313	297	237	-26.0
Biological science[2]	2,717	2,227	2,283	2,178	2,027	1,916	1,892	-31.1
Top 25 percent	1,625	1,385	1,447	1,341	1,311	1,179	1,089	-33.0
Other	1,092	842	836	837	716	737	783	-28.3
Mathematics computer science[2]	264	248	251	221	224	146	149	-43.6
Top 25 percent	173	168	169	148	142	102	100	-42.2
Other	91	80	82	73	82	44	49	-46.2
Psychology social science[2]	4,595	4,205	3,782	3,103	2,760	2,346	1,833	-60.1
Top 25 percent	2,168	1,910	1,681	1,412	1,182	997	885	-59.2
Other	2,427	2,295	2,101	1,691	1,578	1,349	948	-60.9
	Research assistantships							
S E fields[2]	14,991	1,584	16,372	18,139	18,971	18,961	18,756	25.1
Top 25 percent	7,869	8,297	8,623	9,611	10,057	9,841	9,903	25.8
Other	7,122	7,524	7,749	8,528	8,914	9,147	8,853	24.3
Engineering[2]	4,368	4,604	4,868	5,048	5,375	5,295	5,361	22.7
Top 25 percent	2,440	2,524	2,664	2,833	2,887	2,735	2,869	17.6
Other	1,928	2,080	2,204	2,542	2,488	2,560	2,492	29.2
Physical environmental science[2]	6,182	6,476	6,590	7,497	8,030	8,079	7,955	28.7
Top 25 percent	3,549	3,719	3,833	4,173	4,604	4,562	4,467	25.9
Other	2,633	2,757	2,757	3,314	3,426	3,517	3,488	32.5
Biological science[2]	1,905	2,233	2,285	2,714	2,806	2,884	2,929	53.8
Top 25 percent	625	799	826	1,069	1,116	1,205	1,329	112.6
Other	1,280	1,434	1,459	1,645	1,690	1,679	1,600	25.0
Mathematics computer science[2]	742	778	844	970	1,056	1,011	1,116	50.4
Top 25 percent	454	465	498	573	587	551	646	42.3
Other	288	313	346	397	469	460	470	63.2
Psychology social science[2]	1,794	1,730	1,785	1,920	1,704	1,692	1,395	-22.2
Top 25 percent	993	790	802	963	863	761	592	-40.4
Other	801	940	983	957	841	931	803	- 0.2

[1] Distribution by type of major support was not collected in 1978.

[2] Includes only those fields surveyed by the Conference Board. See appendix table 5-5 for a listing of those fields.

SOURCE: National Science Foundation, unpublished tabulations.

Appendix table 5-19. R&D expenditures at doctorate-granting institutions, by source of funds, character of work, and science engineering fields: 1972-84

Source, character and field	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
						Thousand dollars							
Total	$2,568,573	$2,809,160	$2,953,658	$3,338,409	$3,656,888	$3,987,885	$4,540,256	$5,271,643	$5,958,867	$6,695,996	$7,159,254	$7,649,290	$8,321,159
Source of funds													
Federal government	1,754,798	1,938,225	1,990,167	2,241,149	2,465,396	2,677,463	3,004,930	3,534,215	4,030,009	4,482,252	4,671,543	4,874,726	5,288,167
State and local governments	261,026	282,281	294,547	325,209	356,451	365,569	406,509	461,534	481,354	534,047	595,452	606,546	638,116
Industry	73,006	81,783	93,781	110,098	120,087	135,031	166,271	190,733	232,758	284,685	326,984	370,234	446,950
Institutional funds	297,906	310,595	362,517	409,468	436,795	502,930	610,068	716,069	813,577	958,595	1,074,976	1,223,820	1,331,865
Other sources	181,837	196,276	212,646	252,485	278,159	306,892	352,478	369,092	401,169	436,417	490,299	573,964	616,061
Character of work													
Basic research	1,987,822	2,021,690	2,120,593	2,370,779	2,507,788	2,758,513	(1)	3,561,649	3,965,960	4,501,674	4,783,875	5,150,838	5,524,064
Applied research and development	580,751	787,470	833,065	967,630	1,149,100	1,229,372	(1)	1,709,994	1,992,907	2,194,322	2,375,379	2,498,452	2,797,095
Field													
Engineering	335,111	328,206	343,969	377,107	425,182	490,931	591,962	761,142	857,043	952,823	1,021,145	1,099,512	1,184,916
Aeronautical and astronautical	NA	NA	NA	NA	NA	NA	NA	NA	45,742	44,919	59,669	64,163	64,151
Chemical	NA	NA	NA	NA	NA	NA	NA	NA	66,876	82,955	83,586	90,342	95,551
Civil	NA	NA	NA	NA	NA	NA	NA	NA	86,703	106,115	107,016	107,458	127,900
Electrical	NA	NA	NA	NA	NA	NA	NA	NA	183,219	191,922	224,447	258,248	28,698
Mechanical	NA	NA	NA	NA	NA	NA	NA	NA	145,125	147,730	141,268	147,627	173,384
Other engineering	NA	NA	NA	NA	NA	NA	NA	NA	329,378	379,182	405,159	431,674	435,232
Physical sciences	314,656	315,751	322,183	338,445	366,497	410,642	481,447	585,227	659,047	746,336	804,788	877,689	972,863
Astronomy	21,373	23,863	24,185	26,394	26,094	32,117	36,505	47,969	58,087	66,746	72,662	73,378	77,402
Chemistry	103,794	108,060	110,589	114,939	133,613	152,454	175,438	198,788	234,359	272,932	296,640	322,520	358,846
Physics	154,640	162,189	165,323	169,310	179,013	197,861	230,678	286,738	316,094	350,797	360,044	407,981	462,529
Other physical sciences	34,849	21,649	22,086	27,802	27,777	28,210	38,826	51,732	50,507	55,861	75,442	73,810	74,086
Environmental sciences	183,943	203,016	227,989	246,766	279,503	309,283	367,337	443,531	496,188	532,947	542,748	600,925	624,969
Mathematical and computer sciences	67,500	70,616	74,865	82,316	84,661	104,046	121,675	172,417	188,174	217,078	241,755	276,160	339,011
Mathematics	NA	35,587	36,486	37,916	41,330	51,050	57,342	77,141	76,759	86,198	95,082	101,163	119,513
Computer sciences	NA	35,029	38,379	44,490	43,331	52,996	64,333	95,276	111,415	130,880	146,673	174,997	219,498
Life sciences	1,308,592	1,506,802	1,606,025	1,881,524	2,081,677	2,234,749	2,515,138	2,802,489	3,184,002	3,631,982	3,931,719	4,165,671	4,537,762
Agricultural sciences	225,299	274,732	335,840	377,260	406,359	453,787	514,409	591,631	666,756	756,048	825,681	869,463	893,646
Biological sciences	435,296	547,007	500,394	619,719	700,143	758,929	793,613	899,789	1,015,719	1,169,322	1,267,085	1,374,847	1,536,653
Medical sciences	584,676	635,919	713,891	809,763	895,759	947,629	1,128,652	1,234,837	1,410,704	1,596,507	1,719,504	1,795,999	1,969,011
Other life sciences	63,321	49,144	55,900	74,782	79,416	74,404	78,464	76,232	90,823	110,098	119,449	125,362	138,452
Psychology	85,932	70,065	70,145	74,385	74,621	82,199	86,556	93,944	106,864	122,134	128,778	134,224	144,789
Social sciences	191,538	213,118	227,949	242,790	248,467	254,749	264,351	283,183	324,129	350,331	339,441	335,734	341,910
Other sciences	101,301	101,586	80,533	95,076	96,280	101,286	111,790	129,710	143,020	142,365	148,880	159,375	174,939

[1] Data were not collected in 1978

Note NA = Not available

SOURCE National Science Foundation, *Academic Science Engineering R&D Funds, Fiscal Year 1983* (NSF 85-308)

See figures 5-1 and 5-18

Appendix table 5-20. Expenditures for academic R&D, by source: 1960-85

Year	Total	Federal government	Industry	Universities & colleges	Other nonprofit institutions	Total	Federal government	Industry	Universities & colleges	Other nonprofit institutions
	Million dollars					Million constant 1972 dollars[1]				
1960	646	405	40	149	52	929	582	57	214	75
1961	763	500	40	165	58	1,084	711	57	235	82
1962	904	613	40	185	66	1,267	859	56	259	92
1963	1,081	760	41	207	73	1,490	1,047	57	285	101
1964	1,275	917	40	235	83	1,738	1,250	55	320	113
1965	1,474	1,073	41	267	93	1,966	1,431	55	356	124
1966	1,715	1,261	42	304	108	2,228	1,639	55	395	140
1967	1,921	1,409	48	345	119	2,418	1,774	60	434	150
1968	2,149	1,573	55	390	131	2,611	1,911	67	474	159
1969	2,225	1,600	60	420	145	2,582	1,857	70	487	168
1970	2,335	1,648	61	461	165	2,565	1,810	67	506	181
1971	2,500	1,724	70	529	177	2,615	1,803	73	553	185
1972	2,630	1,795	74	574	187	2,630	1,795	74	574	187
1973	2,884	1,985	84	613	202	2,761	1,900	80	587	193
1974	3,023	2,032	96	677	218	2,698	1,813	86	604	195
1975	3,409	2,288	113	749	259	2,766	1,856	92	608	210
1976	3,729	2,512	123	810	284	2,828	1,905	93	614	215
1977	4,067	2,726	139	888	314	2,889	1,937	99	631	223
1978	4,625	3,059	170	1,037	359	3,077	2,035	113	690	239
1979	5,361	3,595	193	1,200	373	3,280	2,199	118	734	228
1980	6,060	4,094	235	1,323	408	3,412	2,305	132	745	229
1981	6,818	4,559	288	1,523	448	3,490	2,338	148	781	230
1982	7,261	4,749	326	1,683	503	3,469	2,275	156	806	241
1983 (Prel.)	7,745	4,960	370	1,830	585	3,559	2,279	170	841	269
1984 (Est.)	8,625	5,500	425	2,080	620	3,818	2,435	188	921	274
1985 (Est.)	9,625	6,150	485	2,300	690	4,108	2,625	207	982	295

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars. See appendix table 2-1 for deflators.

Note: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1984* (NSF 84-319), and preliminary data.

See figure 5-15.

Appendix table 5-21. Relative concentration of Federal obligations for basic research to universities and colleges, by field: 1974-85

Year	All S/E fields	Life sciences	Psychology	Physical sciences	Environmental sciences	Mathematics & computer sciences	Engineering	Social sciences	Other sciences
	Percent								
1974	100.0	54.2	2.5	18.3	9.3	3.2	7.9	3.7	0.8
1975	100.0	53.3	2.3	18.4	9.8	3.4	8.7	3.3	0.8
1976	100.0	54.5	2.1	17.8	9.7	3.5	8.6	3.4	0.4
1977	100.0	52.8	2.1	17.6	10.8	3.7	9.1	3.4	0.6
1978	100.0	53.3	1.9	17.2	11.0	3.8	8.7	3.2	0.7
1979	100.0	55.6	2.0	15.8	11.2	3.4	8.0	2.8	1.2
1980	100.0	53.2	2.3	16.4	11.1	3.5	9.1	2.8	1.0
1981	100.0	53.0	2.3	17.5	9.7	4.1	9.6	2.6	1.4
1982	100.0	55.1	1.8	16.9	9.5	4.4	9.6	1.7	1.0
1983	100.0	55.3	1.8	16.3	9.2	4.8	9.6	1.8	1.1
1984	100.0	56.7	1.8	16.7	8.3	4.4	9.7	1.4	1.0
1985 (Est.)	100.0	58.0	1.8	16.5	7.8	4.1	9.5	1.4	0.9
1986 (Est.)	100.0	55.1	1.8	17.5	8.2	4.7	10.4	1.4	0.9

Note: Detail may not add to totals because of rounding.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables, Fiscal Years 1967-85*, 1984.

Science Indicators—1985

Appendix table 5-22. Federal obligations for basic research to university and college performers, for selected agencies: 1967-86

Year	All agencies	USDA	DOD	NIH	NSF	NASA	Other agencies
	Thousand dollars						
1967	$857,149	$26,025	$148,548	$286,853	$196,970	$59,750	$139,003
1968	835,029	24,833	132,461	302,121	206,476	38,223	130,915
1969	864,339	24,793	151,254	305,714	199,074	45,165	138,339
1970	808,095	25,732	127,099	293,163	200,951	34,102	127,048
1971	879,356	28,334	129,876	328,298	220,323	49,957	122,568
1972	1,021,385	34,846	130,132	389,717	301,218	40,514	124,958
1973	1,048,189	37,209	114,677	390,131	327,163	56,266	122,743
1974	1,144,748	38,135	106,279	513,932	306,938	61,285	118,179
1975	1,260,609	43,290	105,530	545,216	378,721	64,548	123,304
1976	1,341,738	47,004	112,003	600,008	391,923	67,157	123,643
1977	1,555,067	56,130	141,754	677,091	474,892	71,988	133,212
1978	1,759,234	77,712	167,865	767,602	502,019	88,341	155,695
1979	2,079,925	83,967	178,902	965,810	574,137	96,785	180,324
1980	2,320,253	90,245	208,336	1,062,958	642,924	112,751	203,039
1981	2,503,223	102,901	244,405	1,150,213	667,979	124,418	213,307
1982	2,727,[illegible]26	107,576	305,365	1,296,428	674,313	125,876	217,568
1983	3,112,307	117,122	360,432	1,502,084	736,502	140,081	256,086
1984	3,490,727	111,755	405,373	1,733,130	831,736	148,442	260,291
1985 (Est.)	3,985,641	143,009	407,759	2,018,574	944,137	177,500	294,664
1986 (Est.)	4,014,493	128,323	469,885	1,897,489	1,015,561	207,300	295,935
	Thousand constant 1972 dollars[1]						
1967	1,078,989	32,761	186,994	361,094	247,948	75,214	174,979
1968	1,014,493	30,170	160,929	367,053	250,852	46,438	159,051
1969	1,003,063	28,772	175,530	354,780	231,025	52,414	160,542
1970	887,626	28,264	139,608	322,016	220,728	37,458	139,552
1971	919,636	29,632	135,825	343,336	230,415	52,245	128,182
1972	1,021,385	34,846	130,132	389,717	301,218	40,514	124,958
1973	1,003,532	35,624	109,791	373,510	313,225	53,869	117,514
1974	1,021,549	34,031	94,841	458,622	273,905	54,689	105,460
1975	1,022,724	35,121	85,616	442,330	307,254	52,367	100,036
1976	1,017,393	35,641	84,928	454,965	297,182	50,923	93,754
1977	1,104,765	39,876	100,706	481,025	337,377	51,142	94,638
1978	1,170,248	51,694	111,664	510,611	333,945	58,765	103,569
1979	1,272,437	51,369	109,447	590,854	351,240	59,210	110,317
1980	1,306,302	50,808	117,293	598,445	361,966	63,479	114,311
1981	1,283,836	52,775	125,349	589,913	342,588	63,811	109,399
1982	1,306,283	51,528	146,269	620,984	322,993	60,294	104,214
1983	1,429,172	53,782	165,510	689,757	338,202	64,325	117,595
1984	1,545,185	49,469	179,440	767,177	368,171	65,708	115,219
1985 (Est.)	1,701,230	61,042	174,047	861,607	402,995	75,764	125,774
1986 (Est.)	1,647,039	52,647	192,781	778,489	416,658	85,050	121,414

[1] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *Federal Funds for Research and Development, Detailed Historical Tables*, Fiscal Years 1967-85, 1984.

See figure 5-16.

Science Indicators—1985

Appendix table 5-23. Organized research units, by decade of founding

Groupings	Pre-1940	1940-1950	1950-1960	1960-1970	1970-1981	Distribution of current ORU's by field
Biological sciences	5.0	2.2	58.3	22.3	12.2	12.6
Medical sciences (core)[1]	3.7	11.1	7.4	18.5	59.3	2.4
Agricultural sciences	14.6	20.8	2.1	37.5	25.0	4.3
Physical sciences[2]	8.6	4.6	17.7	44.0	25.1	15.9
Engineering	21.5	3.0	6.7	35.6	33.3	12.2
Social sciences[3]	12.2	14.6	4.9	25.5	42.9	34.9
Humanities	3.2	0.0	33.3	25.4	38.1	5.7
Professional[4]	7.5	0.0	8.3	45.9	38.4	12.0
Total (core) percent by Decades	10.7	7.6	15.8	32.0	33.9	100.0
Medical sciences (non-core)	3.7	13.8	2.6	26.4	53.5	

[1] Composed of medical, veterinary, and dental research units which operate in the core milieu.

[2] NSF atmospheric and geological sciences, mathematics, and computer sciences classifications are subsumed under physical sciences.

[3] Psychology is merged with the NSF social sciences list.

[4] Composed of law, business, education, and social work research units.

[5] Composed of medical, veterinary, and dental research units which operate outside the core milieu.

SOURCE: R. Friedman and R. Friedman, *The Role of University Organized Research Units in Academic Science*, NTIS PB 82-253394, 1982.

Science Indicators—1985

Appendix table 5-24. Federal obligations to university-affiliated FFRDC's[1] by location and sponsoring agencies, for R&D and all activities: 1983

Location	Name & supporting agencies	Total obligations	R&D obligations
		Thousand dollars	
Arizona	Kitt Peak National Observatory	$12,018	$12,018
	NSF	12,018	12,018
California	Jet Propulsion Laboratory	428,351	419,511
	HHS	785	785
	NASA	427,526	418,680
	NSF	46	46
	Lawrence Berkeley Laboratory	139,541	119,668
	COM	52	52
	DOE	129,165	109,479
	HHS	10,233	10,046
	NSF	91	91
	Lawrence Livermore Laboratory	547,141	414,612
	DOE	545,913	413,384
	HHS	1,228	1,228
	Stanford Linear Accelerator Center	86,970	75,616
	DOE	86,652	75,298
	HHS	318	318
Colorado	National Center for Atmospheric Research	36,937	36,937
	NSF	36,937	36,937
Illinois	Argonne National Laboratory	204,259	178,437
	DOE	203,672	177,850
	HHS	587	587
	Fermi National Accelerator Laboratory	175,463	107,952
	DOE	175,433	107,952
	NSF	30	0
Iowa	Ames Laboratory	17,327	15,294
	COM	32	32
	DOE	17,295	15,262
Massachusetts	Lincoln Laboratory	266,827	266,827
	DOE	266,827	266,827
New Jersey	Plasma Physics Laboratory	134,060	118,288
	DOE	134,060	118,288
New Mexico	Los Alamos Scientific Laboratory	476,298	422,634
	DOE	473,838	420,174
	HHS	2,439	2,439
	NSF	21	21
	Sacramento Peak Observatory	2,577	2,577
	NSF	2,577	2,577
New York	Brookhaven National Laboratory	167,176	137,694
	USDA	65	65
	DOE	162,276	132,973
	HHS	4,293	4,114
	NSF	321	321
	Other	221	221
Tennessee	Oak Ridge Institute for Nuclear Studies	12,413	11,909
	DOE	8,816	8,336
	HHS	1,856	1,832
	NSF	1,741	1,741
Virginia	Center for Naval Analysis	18,035	18,035
	DOD	17,937	17,937
	LABOR	98	98
West Virginia	National Radio Astronomy Observatory	16,773	16,773
	NSF	16,773	16,773
Puerto Rico	National Astronomical and Ionospheric center	6,425	6,425
	NSF	6,425	6,425
Chile	Cerro Tololo Interamerican Observatory	6,460	6,460
	NSF	6,460	6,460

[1] Federally funded research and development centers.

SOURCE: National Science Foundation, *Federal Support to Universities, Colleges, and Selected Nonprofit Institutions*, Fiscal Year 1983, (NSF 85-321).

Appendix table 5-25. R&D expenditures at university-administered federally funded research and development centers, by character of work and science/engineering field: 1972-84

Character and field	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
	Thousand dollars												
Total	$753,243	$816,923	$865,098	$986,736	$1,146,712	$1,383,814	$1,716,911	$1,934,797	$2,245,773	$2,485,853	$2,478,721	$2,736,652	$3,117,716
Character of work													
Basic research	243,870	296,492	285,082	308,981	358,811	402,168	(1)	718,303	785,774	863,179	869,701	982,272	1,052,027
Applied research and development	509,373	520,431	580,016	677,755	787,901	981,646	(1)	1,216,494	1,459,999	1,622,674	1,609,020	1,754,380	2,065,689
Field													
Engineering	195,393	251,539	259,080	275,682	299,683	380,420	522,213	561,083	644,910	656,426	636,158	944,952	1,109,866
Aeronautical and astronautical	NA	NA	NA	NA	NA	NA	NA	NA	24,778	60,339	59,409	69,057	86,022
Chemical	NA	NA	NA	NA	NA	NA	NA	NA	38,406	47,454	44,988	45,832	46,718
Civil	NA	NA	NA	NA	NA	NA	NA	NA	18,874	16,052	17,952	13,378	13,596
Electrical	NA	NA	NA	NA	NA	NA	NA	NA	200,981	169,059	171,470	316,652	394,283
Mechanical	NA	NA	NA	NA	NA	NA	NA	NA	135,858	185,448	181,017	339,573	398,073
Other engineering	NA	NA	NA	NA	NA	NA	NA	NA	226,013	178,074	161,322	160,460	171,174
Physical sciences	426,027	425,107	455,418	523,160	622,887	736,802	854,455	1,003,562	1,127,323	1,270,539	1,315,626	1,196,457	1,326,957
Astronomy	28,089	28,055	29,944	31,153	32,452	41,500	38,452	46,099	59,025	67,578	65,885	73,498	80,188
Chemistry	74,375	73,114	64,920	69,658	96,268	111,564	97,529	101,142	150,540	167,148	161,548	200,505	232,052
Physics	305,086	318,002	268,187	322,464	376,632	447,110	568,040	584,519	829,217	950,865	982,245	885,500	982,449
Other physical sciences	18,477	5,936	92,367	99,885	117,535	136,628	150,434	271,802	88,541	84,948	105,948	36,954	32,268
Environmental sciences	36,684	40,647	47,864	63,175	77,476	100,981	128,217	141,100	174,724	186,526	157,962	154,642	174,197
Mathematical and computer sciences	41,174	53,178	54,339	62,416	71,641	78,584	119,203	126,850	162,114	226,627	219,197	289,614	349,718
Mathematics	NA	14,744	16,002	17,715	22,063	15,358	8,100	6,614	31,089	38,561	42,091	65,340	81,217
Computer sciences	NA	38,434	38,337	44,701	49,578	63,226	111,103	120,236	131,025	188,066	177,106	224,274	268,501
Life sciences	35,854	33,964	34,367	42,284	50,198	57,949	58,439	73,441	76,889	85,164	84,269	104,484	106,555
Agricultural sciences	NA	35	NA	NA	NA	354	1,206	1,551	645	570	2,528	1,008	639
Biological sciences	28,810	24,344	26,211	31,661	38,253	43,569	48,154	62,659	57,006	66,406	62,180	76,437	82,986
Medical sciences	3,656	3,312	3,877	4,963	5,081	4,761	7,963	7,179	8,194	8,453	8,575	9,555	9,079
Other life sciences	3,388	6,273	4,279	5,660	6,864	9,265	1,116	2,052	11,044	9,735	10,986	17,484	13,851
Psychology	1,428	898	850	306	92	87	103	110	135	147	155	194	240
Social sciences	8,568	169	330	795	1,288	3,301	5,119	5,861	17,449	20,984	21,412	21,067	18,056
Other sciences	8,115	11,421	12,850	18,918	23,447	25,690	29,162	22,790	42,229	39,440	43,942	25,242	32,127

[1] Data were not collected in 1978

Note: NA = Not available

SOURCE: National Science Foundation, *Academic Science Engineering: R&D Funds* (NSF 83-308).

See figure 5-18 and 5-19

Appendix 5-26. Doctoral scientists and engineers, by type of employer and primary work activity: 1983

Type of employers	All activities	Research & Development: Basic research	Research & Development: Applied research	Research & Development: Development	Management & administration: R&D	Management & administration: Other than R&D	Teaching	Consulting	Sales & professional services	Other[1] activities
Total	369.320	57.137	47.374	20.277	31.418	30.395	108.236	12.746	29.820	31,917
Business and industry	113.463	6.731	23.463	16.331	20.066	5,462	1.301	10,673	15,581	13,855
Educational Institutions	196.050	39.530	13.649	1.543	3.024	17.702	105.850	757	5,271	8,724
Federal Government	25.793	6.388	6.490	1.000	5.400	1,760	235	383	805	3,332
Other employers[2]	34,014	4.488	3.772	1.403	2.928	5.471	850	933	8.163	6,006

[1] Includes 7.754 individuals who did not report primary work activity

[2] Includes nonprofit organizations, hospitals clinics, military commissioned corps, state, local, and other government government, other employers, and 876 individuals who did not report type of employer

Note Detail may not add to totals because of rouding Statistics based on these rounded numbers may be slightly different from those presented in the text

SOURCE National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States, 1983* (NSF 85-303), p.41

Science Indicators—1985

Appendix table 5-27. Academic[1] doctoral scientists and engineers, by primary work activity and field: 1981 and 1983

S E field	Total	Research & Development: Total	Research & Development: Basic research	Research & Development: Applied research	Research & Development: Development	Research & Development: Management of R&D	Teaching	Consulting	Other[1]
					1981				
All S E fields	179.000	56.800	37.800	13.700	1.000	4,300	99,000	800	22.400
Physical scientists	26.900	10.600	7.800	1,700	300	800	14,200	100	2,000
Mathematical scientists	12.300	2.000	1.600	300	(2)	(2)	9.200	(2)	1,100
Computer specialists	3.000	900	400	200	300	100	1,500	100	500
Environmental scientists[3]	6.600	2.800	1,700	600	100	400	3,400	(2)	400
Engineers	18.000	5.100	1.600	2.300	200	1,000	10,500	200	2,200
Life scientists	55,500	27.600	20.200	6.100	200	1,200	20.700	200	7,000
Psychologists	19.200	3,500	2.100	1.100	(2)	300	11,700	100	3,900
Social scientists	37.500	4.300	2.400	1.300	(2)	600	28,000	200	5,000
					1983				
All S E fields	187.600	57.600	39.400	13.600	1.500	3.000	100.500	700	28.800
Physical scientists	26.500	10.200	7.500	1.600	300	900	13,000	(2)	3,200
Mathematical scientists	12.800	2.100	1,700	300	(2)	100	9,200	100	1,400
Computer specialists	3,900	1.100	500	200	300	100	2,100	(2)	1,600
Environmental scientists[3]	6.500	2.600	1.800	600	(2)	300	3.300	(2)	700
Engineers	20.200	5.900	2.200	2.400	500	700	11,200	100	3,100
Life scientists	57,300	27.300	21.100	5.200	200	800	20.800	300	8,900
Psychologists	19.400	3.200	2.000	1.000	(2)	100	11,500	100	4.600
Social scientists	41.000	5.200	2.700	2.200	100	200	29.300	100	6.500

[1] Includes individuals employed in four-year colleges and universities only

[2] Fewer than 50 individuals

[3] Includes earth scientists, oceanographers, and atmospheric scientists

Note Detail may not add to totals because of rounding

SOURCE National Science Foundation, *Characteristics of Doctoral Scientists and Engineers in the United States 1983* (NSF 85-303) and earlier years

See figure 5-17

Science Indicators—1985

Appendix table 5-28. Academic[1] doctoral scientists and engineers, by age and field: 1977, 1981, and 1983

Fields		Number	Age (years)				
			Under 30	30-39	40-49	50-59	60 +
			Percent				
All S&E's	1977	156,452	3.4	41.2	29.5	18.9	6.9
	1981	179,010	2.6	35.4	32.3	20.6	9.1
	1983	187,554	1.8	31.4	34.8	21.6	10.4
Physical scientists	1977	25,544	4.2	41.4	30.7	16.8	6.9
	1981	26,897	3.5	30.5	34.4	20.7	10.9
	1983	26,453	2.5	24.4	38.8	22.6	11.8
Mathematics	1977	11,774	4.5	48.7	28.1	13.1	5.7
	1981	12,294	3.2	34.6	38.5	16.5	3.8
	1983	12,770	2.2	28.2	42.3	19.1	8.2
Computer scientists	1977	2,118	4.6	52.2	27.9	13.4	1.9
	1981	2,954	3.0	45.4	31.6	15.5	4.5
	1983	3,905	2.1	45.8	32.0	13.1	3.4
Environmental scientists	1977	NA	NA	NA	NA	NA	NA
	1981	6,611	3.3	33.1	37.7	17.8	8.1
	1983	6,519	1.8	35.2	31.6	21.2	10.1
Life scientists	1977	46,267	3.5	42.0	27.6	19.5	7.3
	1981	55,528	3.0	39.4	29.6	19.6	8.5
	1983	57,315	1.9	34.9	32.8	20.7	9.6
Psychologists	1977	16,652	5.1	41.7	28.1	19.3	5.7
	1981	19,195	3.1	41.5	27.7	20.1	7.5
	1983	19,377	1.5	37.8	30.5	21.7	8.4
Social scientists	1977	32,261	2.2	38.4	29.2	21.1	8.8
	1981	37,513	1.2	32.1	37.2	24.5	13.9
	1983	40,966	1.1	29.4	34.1	22.4	12.8
Engineers	1977	15,709	1.8	36.3	36.0	11.7	4.9
	1981	18,018	1.2	27.3	38.0	25.8	10.9
	1983	20,249	2.1	26.0	38.0	24.1	9.7

[1] Include individuals employed in four-year colleges and universities only.

Note: NA = Not available.

SOURCE: National Science Foundation, *Characteristics of U.S. Scientists and Engineers, 1983*, (NSF 85-303) and earlier years.

Science Indicators—1985

Appendix table 5-29. Academic[1] doctoral scientists and engineers who teach[2], by field and rank: 1981 and 1983

S/E field	Total	Academic rank Professor	Associate professor	Assistant professor	Instructor	Other	No report
				1981			
All S/E fields	130,372	57,136	38,214	28,655	1,235	4,806	326
Physical scientists	18,480	9,938	4,802	2,701	134	844	61
Mathematical scientists	10,821	4,954	3,362	2,123	160	197	25
Computer specialists	1,950	579	717	549	30	75	0
Environmental scientists[3]	4,427	1,972	1,319	1,045	6	85	0
Engineers	13,190	7,212	3,684	1,940	0	354	0
Life scientists	34,675	13,650	10,369	8,369	531	1,646	110
Psychologists	15,025	5,830	4,366	3,928	101	700	100
Social scientists	31,804	13,001	9,595	8,000	273	905	30
				1983			
All S/E fields	135,990	62,358	40,789	26,529	745	4,171	1,398
Physical scientists	17,656	10,546	4,074	2,281	102	521	132
Mathematical scientists	11,289	5,295	3,523	2,148	115	132	76
Computer specialists	2,559	842	898	688	5	117	9
Environmental scientists[3]	4,505	2,073	1,291	957	4	129	51
Engineers	14,902	8,047	4,232	2,262	2	253	106
Life scientists	35,415	14,911	10,693	7,497	258	1,669	387
Psychologists	14,956	6,157	4,822	3,195	110	429	243
Social scientists	34,708	14,487	11,256	7,501	149	921	394

[1] Includes individuals employed in four-year colleges and universities only.

[2] Includes individuals who indicated teaching as a primary or secondary work activity.

[3] Includes earth scientists, oceanographers, and atmospheric scientists.

SOURCE: National Science Foundation, *Characteristics of U.S. Scientists and Engineers: 1983* (NSF 85-303) and earlier years.

See figure 5-12

Science Indicators—1985

Appendix 5-30. Distribution of research articles[1] written by U.S. scientists and engineers, by field and research sector: 1973 and 1982

Field[2]	Year	Total	Universities and colleges	Federal government	Industry[3]	Nonprofit institutions[3]	FFRDC's[4]	All others
			(Percent)					
All S E fields	1973	100	65	11	11	7	3	3
	1982	100	69	10	10	7	3	2
Clinical medicine	1973	100	64	12	4	15	1	5
	1982	100	69	11	3	14	0	3
Biomedicine	1973	100	76	9	3	7	2	2
	1982	100	79	9	3	7	1	0
Biology	1973	100	69	20	4	3	1	4
	1982	100	76	15	3	3	0	3
Chemistry	1973	100	68	8	18	2	3	1
	1982	100	71	7	16	2	3	1
Physics	1973	100	62	9	15	3	11	0
	1982	100	61	6	20	2	10	0
Earth and space sciences	1973	100	67	16	6	3	6	2
	1982	100	67	16	6	3	7	1
Engineering and technology	1973	100	39	9	41	3	5	2
	1982	100	44	7	39	3	5	2
Mathematics	1973	100	92	3	3	2	1	0
	1983	100	91	3	3	2	1	0

[1] Based on the articles, notes and reviews by U S. authors in over 2,100 of the influential journals on the 1973 Science Citation Index Corporate Tapes of the Institute for Scientific Information.

[2] See appendix table 1-8 for the subfields included in those fields.

[3] Including the federally funded research and development centers (FFRDCs) administered by these sectors.

[4] FFRDC's administered by universities.

Note: Detail may not add to the totals because of rounding. Likewise, counts of articles may differ slightly from those of other tables in this report for technical reasons.

SOURCE: Computer Horizons, Inc., unpublished data.

Science Indicators—1985

Appendix table 5-31. Science and technology articles[1] by U.S. college and university authors, by field: 1973-82

Field[2]	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	(1973-1982)
	Articles										Percent change
All S/E fields	67,573	65,197	63,511	66,019	65,024	66,863	67,170	66,987	72,794	73,695	9.1
Clinical medicine	20,781	19,996	19,872	21,498	22,120	23,417	22,758	23,313	25,276	25,172	21.1
Biomedicine	12,322	11,960	12,238	12,569	12,628	13,019	13,711	13,686	14,596	15,257	23.8
Biology	7,734	7,498	7,099	7,627	7,169	7,138	7,661	7,193	8,117	8,567	10.8
Chemistry	7,210	7,091	6,694	6,537	6,276	6,525	6,363	6,554	6,976	7,250	0.6
Physics	7,259	7,226	6,912	6,941	6,772	6,774	6,844	6,964	7,482	7,583	4.5
Earth and space sciences	3,769	3,611	3,209	3,490	3,347	3,499	3,526	3,262	3,614	3,511	-6.8
Engineering and technology	4,715	4,346	4,115	4,165	3,870	3,790	3,711	3,614	4,087	4,039	-14.3
Mathematics	3,784	3,466	3,373	3,194	2,842	2,702	2,599	2,400	2,646	2,316	-38.8

[1] Based on articles, notes, and reviews from over 2,100 of the influential journals covered on the 1973 Science Citation Index Corporate Tapes of the Institute for Scientific Information.

[2] See appendix table 1-8 for the subfields included in those fields.

Note: Detail may not add to the totals because of rounding. Likewise, counts of articles may differ slightly from those of other tables in this report for technical reasons.

SOURCE: Computer Horizons, Inc., unpublished data.

See figure 5-13.

Science Indicators—1985

Appendix table 5-32. Proportion of fulltime science and engineering faculty engaged in paid consulting, by type of institution and science/engineering field: 1984

Field	Major research university	Other doctoral	Comprehensive colleges & universities	Baccalaureate institutions	Other institutions[1]
	Percent				
All S&E fields	83	84	77	80	87
Physical sciences	78	89	74	82	88
Environmental sciences	100	95	100	50	75
Mathematics and statistics	79	78	74	88	81
Biological sciences	76	73	71	77	0
Engineering	87	93	82	0	96
Computer sciences	100	79	100	83	0

[1] Includes technical and engineering institutions.

SOURCE: F. Darknell and D. Nasatir, unpublished tabulations, 1985.

Science Indicators—1985

Appendix table 5-33. Current fund expenditures for research equipment at universities and colleges by science/engineering field and source of funds: fiscal years 1982, 1983, and 1984

Field	Total					Federally financed					Non-federal				
				Percent change					Percent change					Percent change	
	1982	1983	1984	1982-83	1983-84	1982	1983	1984	1982-83	1983-84	1982	1983	1982	1982-83	1983-84
	(Thousand dollars)			(Percent)		(Thousand dollars)			(Percent)		(Thousand dollars)			(Percent)	
Total	$408.479	$435.178	$518.068	6.5	19.0	$266.780	$272.819	$335.486	2.3	23.0	$141.699	$162.359	$182.583	14.6	12.5
Engineering	65.843	75.018	90.610	13.9	20.8	43.213	48.958	59.278	13.3	21.1	22.630	26.060	31.332	15.2	20.2
Aeronautical and astronautical	2.261	2.892	5.353	27.9	85.1	1.366	2.091	4.036	53.1	93.0	895	801	1.317	-10.5	64.4
Chemical	6.439	6.243	7.438	-3.0	19.1	3.821	3.614	4.019	-5.4	11.2	2.618	2.629	3.419	0.4	30.0
Civil	5.158	6.148	6.641	19.2	8.0	2.823	3.438	4.164	21.8	21.1	2.335	2.710	2.477	16.1	-8.6
Electrical	18.444	20.758	23.106	12.5	11.3	14.058	14.519	15.777	3.3	8.7	4.386	6.239	7.329	42.2	17.5
Mechanical	7.379	10.018	14.272	35.8	42.5	4.208	6.581	10.021	56.4	52.3	3.171	3.437	4.251	8.4	23.7
Other, n.e.c.	26.167	28.959	33.799	10.7	16.7	16.937	18.715	21.216	10.5	13.6	9.230	10.244	12.538	11.0	22.4
Physical sciences	78.126	79.375	107.439	1.6	35.4	62.653	62.055	86.738	-1.0	39.8	15.473	17.320	20.702	11.9	19.5
Astronomy	5.127	4.243	5.761	-17.2	35.8	3.941	3.465	4.278	-12.1	23.5	1.186	778	1.483	-34.4	90.6
Chemistry	33.205	32.814	43.456	-1.2	32.4	24.908	23.551	33.100	-5.4	40.5	8.297	9.263	10.355	11.6	11.8
Physics	33.228	35.708	47.606	7.5	33.3	28.537	29.587	40.474	3.7	36.8	4.691	6.121	7.132	30.5	16.5
Other, n.e.c.	6.566	6.610	10.617	0.7	60.6	5.267	5.452	8.886	3.5	63.0	1.299	1.158	1.731	-10.9	49.5
Environmental sciences	28.317	31.521	40.806	11.3	29.5	18.436	19.649	29.477	6.6	50.0	9.881	11.872	11.329	20.1	-4.6
Atmospheric	4.529	5.106	6.710	12.7	31.4	3.284	3.615	4.928	10.1	36.3	1.245	1.491	1.782	19.8	19.5
Earth sciences	10.580	11.891	16.012	12.4	34.7	6.360	6.621	10.032	4.1	51.5	4.220	5.270	5.980	24.9	13.5
Oceanography	8.873	10.958	13.674	23.5	24.8	5.990	6.840	11.336	14.2	65.7	2.883	4.118	2.338	42.8	-43.2
Other, n.e.c.	4.335	3.566	4.410	-17.7	23.7	2.802	2.573	3.181	-8.2	23.6	1.533	993	1.229	-35.2	23.8
Mathematical computer sciences	15.228	18.283	23.595	20.1	29.1	9.832	11.705	17.268	19.1	47.5	5.396	6.578	6.326	21.9	-3.8
Mathematics	2.556	2.668	4.539	4.4	70.1	1.617	1.476	3.212	-8.7	117.6	939	1.192	1.327	26.9	11.3
Computer sciences	12.672	15.615	19.056	23.2	22.0	8.215	10.229	14.056	24.5	37.4	4.457	5.386	4.999	20.8	-7.2
Life sciences	199.570	205.680	225.572	3.1	9.7	120.214	117.039	128.837	-2.6	10.1	79.356	88.641	96.734	11.7	9.1
Agricultural sciences	38.921	37.985	37.233	-2.4	-2.0	11.706	10.281	12.028	-12.2	17.0	27.215	27.704	25.205	1.8	-9.0
Biological sciences	75.887	75.271	84.634	-0.8	12.4	53.204	51.078	58.011	-4.0	13.6	22.683	24.193	26.623	6.7	10.0
Medical sciences	78.811	85.829	95.855	8.9	11.7	51.551	51.745	54.194	0.4	4.7	27.260	34.084	41.661	25.0	22.2
Other, n.e.c.	5.951	6.595	7.849	10.8	19.0	3.753	3.935	4.604	4.8	17.0	2.198	2.660	3.245	21.0	22.0
Psychology	5.737	6.629	7.066	15.5	6.6	4.219	4.749	5.016	12.6	5.6	1.518	1.880	2.050	23.8	9.0
Social sciences	7.147	8.961	12.724	25.4	42.0	2.907	2.917	3.484	0.3	19.4	4.240	6.044	9.240	42.5	52.9
Economics	1.704	1.911	2.414	12.1	26.3	674	728	1.014	8.0	39.3	1.030	1.183	1.400	14.9	18.3
Political science	765	767	834	0.3	8.7	312	319	297	2.2	-6.9	453	448	537	1.1	19.9
Sociology	2.056	1.472	1.567	-28.4	6.5	948	944	963	-0.4	2.0	1.108	528	604	52.3	14.4
Other, n.e.c.	2.622	4.811	7.909	83.5	64.4	973	926	1.210	-4.8	30.7	1.649	3.885	6.699	135.6	72.4
Other sciences, n.e.c.	8.461	9.711	10.257	14.8	5.6	5.306	5.747	5.387	8.3	-6.3	3.155	3.964	4.870	25.6	22.9

SOURCES: National Science Foundation, unpublished tabulations, 1984

Science Indicators—1985

Appendix table 5-34. Cost estimates for building a national program for modern academic computing facilities: fiscal years 1984-86

	1984[1]	1985	1986
	Million dollars		
Total	$70	$188	$261
Local facilities	45	91	107
Supercomputers	15	70	110
Networks	2	7	11
Advanced computer systems and computational mathematics	8	20	33

[1] The NSF program for Advanced Scientific Computing was established in April 1984.

SOURCE: National Science Foundation, *A National Computing Environment for Academic Research* (NSF 83-84), 1983.

Science Indicators—1985

Appendix table 5-35. Capital expenditures at universities and colleges, by science and engineering field and source of funds: fiscal years 1976-84

Field	1976	1977	1979	1980	1981	1982	1983	1984
	Thousand dollars							
All sources	$1,043,153	$960,014	$696,218	$794,512	$952,672	$969,147	$1,099,846	$1,216,512
Engineering	81,678	87,718	87,128	89,297	103,329	144,457	135,206	143,108
Physical sciences	73,755	65,216	64,685	77,154	87,813	82,100	97,594	116,483
Environmental sciences	49,304	28,351	25,153	36,208	35,025	42,365	41,114	36,826
Mathematical computer sciences	24,684	25,136	27,282	32,318	30,517	34,328	53,152	49,976
Life sciences	706,961	642,493	428,293	459,057	597,635	590,353	678,959	741,674
Psychology	9,131	12,702	7,060	17,982	10,991	12,798	17,039	35,237
Social sciences	44,303	31,798	21,358	35,073	45,138	30,797	40,977	52,062
Other sciences, n.e.c.	53,337	66,600	35,259	47,423	42,224	31,949	35,805	41,146
Federal sources	206,890	195,519	164,460	149,563	153,800	116,651	132,422	142,970
Engineering	20,200	17,219	20,927	20,438	17,601	18,136	16,389	24,227
Physical sciences	19,195	21,894	32,186	22,463	25,529	20,154	18,706	19,321
Environmental sciences	6,428	9,307	8,220	8,033	6,866	4,404	3,646	3,502
Mathematical computer	2,052	1,882	2,983	5,653	4,944	3,798	4,512	5,301
Life sciences	153,570	137,369	90,796	86,105	89,410	66,004	81,197	85,658
Psychology	1,967	2,398	1,740	2,002	1,580	1,023	1,392	1,040
Social sciences	1,806	2,109	2,076	1,528	6,376	1,374	5,066	3,061
Other sciences, n.e.c.	1,672	3,341	5,532	3,341	1,494	1,758	1,514	860
Other sources	836,263	764,495	531,758	644,949	798,872	852,496	967,424	1,073,543
Engineering	61,478	70,499	66,201	68,859	85,728	126,321	118,817	118,881
Physical sciences	54,560	43,322	32,499	54,691	62,284	61,946	78,888	97,163
Environmental sciences	42,876	19,044	16,933	28,175	28,159	37,961	37,468	33,324
Mathematical computer sciences	22,632	23,254	24,299	26,665	25,573	30,530	48,640	44,675
Life sciences	553,391	505,124	337,497	372,952	508,225	524,349	597,762	656,016
Psychology	7,164	10,304	5,320	15,980	9,411	11,775	15,647	34,197
Social sciences	42,497	29,689	19,282	33,545	38,762	29,423	35,911	49,001
Other sciences, n.e.c.	51,665	63,259	29,727	44,082	40,730	30,191	34,291	40,286

Note: Data not collected in 1978

SOURCE: National Science Foundation, unpublished tabulations

Science Indicators—1985

Appendix table 5-36. Average expenditures for library materials (other than serials) and average number of volumes added to research libraries at the top 50[1] academic R&D institutions: 1980-83

Institutional rank	1980	1981	1982	1983
	Average library expenditures[2]			
Total, top 50	1,055	1,147	1,262	1,393
First 10	1,117	1,121	1,312	1,518
11-20	1,498	1,817	1,905	2,199
21-30	1,027	1,077	1,722	1,134
31-40	719	758	901	1,010
41-50	824	812	961	1,002
	Average number volumes added			
Total, top 50	99,846	94,951	90,619	99,525
First 10	109,586	101,761	95,740	108,842
11-20	142,503	143,027	134,371	146,499
21-30	89,654	85,888	82,251	93,916
31-40	70,830	63,803	62,252	63,108
41-50	74,779	70,661	70,227	79,855

[1] As ranked by academic R&D expenditures in 1982.

[2] Dollars in thousands

SOURCES: Association of Research Libraries, special tabulations, 1984.

Science Indicators—1985

Appendix table 6-1. Distribution of ACT Assessment Scores, for national samples of college-bound students: 1973-84

Scores	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Composite:												
Mean	19.2	18.9	18.6	18.3	18.4	18.5	18.6	18.5	18.5	18.4	18.3	18.5
S.D.	5.7	5.7	5.8	5.9	5.9	5.9	5.8	5.8	5.8	5.8	6.0	5.9
Mathematics:												
Mean	19.1	18.3	17.6	17.5	17.4	17.5	17.5	17.4	17.3	17.2	16.9	17.3
S.D.	7.2	7.4	7.9	7.6	7.8	7.7	7.6	7.6	7.9	8.0	8.2	8.0
Science:												
Mean	20.8	20.8	21.1	20.8	20.9	20.9	21.1	21.1	21.0	20.8	20.9	21.0
S.D.	6.3	6.4	6.3	6.6	6.5	6.5	6.3	6.2	6.1	6.3	6.5	6.3
Number	73,744	73,995	71,443	69,166	74,356	76,977	78,021	82,220	83,576	80,452	83,530	84,956

SOURCE: Senta A. Raizen and Lyle V. Jones (eds.), *Indicators of Precollege Education in Science and Mathematics: A Preliminary Review* (Washington, D.C.: National Academy Press, 1985).

Appendix table 6-2. SAT takers scoring 650 or 700 and above, by test and gender: 1975-84

Scores	1975		1977		1978		1979		1980		1981		1982		1983		1984	
	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total
Verbal																		
Male																		
700 and above	5,573	1.2	5,286	1.2	5,169	1.1	6,566	1.4	4,945	1.1	5,171	1.1	4,142	0.9	4,756	1.1	4,891	1.1
650 and above	16,332	3.6	14,980	3.3	15,973	3.5	17,294	3.8	13,997	3.1	15,136	3.3	14,740	3.3	14,270	3.2	14,779	3.4
Female																		
700 and above	4,566	1.0	5,475	1.2	4,735	1.0	5,793	1.2	5,082	1.0	4,646	0.9	3,725	0.8	4,007	0.8	3,842	0.8
650 and above	13,757	3.1	14,995	3.2	14,717	3.0	15,379	3.1	13,880	2.8	13,576	2.7	13,280	2.7	12,078	2.5	12,018	2.5
Total																		
700 and above	10,139	1.1	10,761	1.2	9,904	1.0	12,359	1.3	10,027	1.1	9,817	1.0	7,867	0.8	8,763	1.0	8,733	1.0
650 and above	30,089	3.4	29,975	3.2	30,690	3.2	32,673	3.4	27,877	2.9	28,712	3.0	28,020	3.0	26,348	2.9	26,797	3.0
Mathematics																		
Male																		
700 and above	24,472	5.4	25,178	5.6	24,904	5.5	23,566	5.2	21,846	4.8	20,607	4.5	22,397	5.0	23,647	5.4	23,180	5.4
650 and above	52,337	11.6	56,144	12.5	53,731	11.8	51,635	11.3	50,975	11.2	49,605	10.9	50,795	11.3	52,496	11.9	54,699	12.6
Female																		
700 and above	6,154	1.4	6,161	1.3	6,563	1.3	6,040	1.2	6,365	1.3	5,437	1.1	6,171	1.3	7,020	1.5	7,379	1.6
650 and above	18,128	4.1	19,136	4.0	19,215	3.9	18,308	3.7	19,828	4.0	18,278	3.7	18,694	3.8	20,820	4.4	23,810	5.0
Total																		
700 and above	30,626	3.4	31,339	3.4	31,467	3.3	29,606	3.1	28,211	3.0	26,044	2.7	28,568	3.0	30,667	3.3	30,559	3.4
650 and above	70,465	7.9	75,280	8.1	72,946	7.7	69,943	7.3	70,803	7.5	67,883	7.2	69,489	7.4	73,316	8.0	78,509	8.7

SOURCE: Educational Testing Service, unpublished data

Appendix table 6-3. Advanced placement examinations taken, percent of total, by subject: 1974-83

Subject	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
	Percent									
American history	18.1	18.7	18.9	19.6	19.9	20.2	20.0	20.2	20.3	20.8
Art	0.9	1.0	1.0	0.9	1.0	1.0	1.1	1.1	1.2	1.1
Biology	9.4	9.7	9.6	9.7	9.3	9.2	8.5	8.5	8.4	8.4
Chemistry	4.8	4.9	5.4	5.1	5.1	5.0	5.1	5.0	5.0	4.9
English	30.5	29.9	29.8	29.5	29.6	30.1	30.6	30.9	31.0	30.9
European history	5.0	5.1	5.3	4.9	4.8	5.0	5.1	5.2	5.3	5.5
French	3.5	3.5	3.4	3.3	3.3	3.2	3.1	3.0	3.1	2.9
German	0.7	0.7	0.6	0.6	0.6	0.5	0.8	0.8	0.8	0.7
Latin	0.8	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7
Mathematics	20.3	19.9	19.3	18.7	18.4	17.7	17.4	17.2	16.9	16.8
Music	0.4	0.4	0.4	0.3	0.7	0.7	0.6	0.4	0.3	0.3
Physics	3.5	3.7	3.7	3.8	3.7	3.6	3.8	3.6	3.6	3.5
Spanish	2.1	1.8	1.8	2.8	2.9	3.1	3.2	3.4	3.4	3.5
Examinations taken	79,036	85,786	98,898	108,870	122,561	139,544	160,214	178,159	188,933	211,160

SOURCE: Educational Testing Service, unpublished data.

Science Indicators—1985

Appendix table 6-4. Science enrollments in junior and senior high schools, by course and grade: 1981/82

	Junior high				Senior high			
Courses	Total	Grade 7	Grade 8	Grade 9	Total	Grade 10	Grade 11	Grade 12
	Thousands							
All courses	10,151	3,445	3,341	3,465	9,623	3,366	3,186	3,083
Science courses	8,691	3,095	2,996	2,600	5,365	2,765	1,546	1,054
General science	2,698	934	882	882	225	141	51	33
Life science	1,939	1,434	411	94	0	0	0	0
Biology	533	115	55	363	2,261	1,953	201	107
Physical science [1]	1,493	143	537	813	220	120	66	34
Chemistry	0	0	0	0	1,132	165	740	227
Physics	0	0	0	0	504	11	130	363
Earth sciences	1,459	313	876	270	118	63	38	17
Other sciences	569	156	235	178	905	312	320	273
	Percent of grade level							
All courses	100	100	100	100	100	100	100	100
Science courses	86	90	90	75	56	82	48	34
General science	27	27	26	25	2	4	2	1
Life science	19	42	12	3	0	0	0	0
Biology	5	3	2	10	23	58	6	3
Physical science [1]	15	4	16	23	2	4	2	1
Chemistry	0	0	0	0	12	5	23	7
Physics	0	0	0	0	5	0	4	12
Earth sciences	14	9	26	8	1	2	1	1
Other sciences	6	5	7	5	9	9	10	9

[1] Does not include the separate physics and chemistry courses for grades 10-12.

SOURCE: Hueftle, S.J., S.L. Rakow, and W.W. Welch, *Images of Science: A Summary of Results from the 1981-82 National Assessment in Science* (Minneapolis, MN: University of Minnesota, 1983).

Science Indicators—1985

Appendix table 6-5. Science enrollment as percent of total in grades 7-12, by subject and region: 1981/82

	Junior high school											
	Grade 7				Grade 8				Grade 9			
Courses	NE	SE	C	W	NE	SE	C	W	NE	SE	C	W
Total science	100	97	91	74	95	86	89	82	94	74	80	60
General science	34	29	39	9	36	17	35	16	34	28	25	17
Life sciences	37	46	31	53	8	10	18	11	3	1	4	3
Biology	6	1	4	2	1	4	1	1	14	9	11	7
Physical sciences	7	0	7	2	21	13	14	17	22	33	12	27
Earth sciences	8	16	7	7	19	39	16	34	17	3	7	4
Other sciences	9	5	3	1	10	3	5	3	4	0	11	2

	Senior high school											
	Grade 10				Grade 11				Grade 12			
Courses	NE	SE	C	W	NE	SE	C	W	NE	SE	C	W
Total science	90	80	72	84	65	40	43	45	45	21	33	28
Biology	63	59	52	59	8	7	4	7	5	3	3	3
Chemistry	9	4	4	3	35	19	20	19	6	6	10	7
Physics	0	0	1	0	6	3	4	3	19	10	11	7
Advanced science	0	1	0	0	1	1	1	2	3	2	2	2
Other sciences	18	16	15	22	15	10	14	14	12	0	7	9

SOURCE: Hueftle, S.J., S.L. Rakow, and W.W. Welch, *Images of Science. A Summary of Results from the 1981-82 National Assessment in Science* (Minneapolis, MN: University of Minnesota, 1983).

Science Indicators—1985

Appendix table 6-6. Items scored correctly on the International Survey of Eighth Grade Mathematics, by selected countries: 1981/82

Topic	United States	British Columbia	Japan	International [1]
	Average percent			
Arithmetic	51	58	60	51
Algebra	43	48	60	43
Geometry	38	42	58	41
Statistics	57	61	71	55
Measurement	42	52	69	51

[1] The countries included, in addition to the United States, were: Belgium (Flemish); Belgium (French); Canada (British Columbia); Canada (Ontario); England and Wales; Finland; France; Hong Kong; Hungary; Israel; Japan; Luxembourg; Netherlands; New Zealand; Nigeria; Scotland; Switzerland; Sweden; Thailand.

SOURCE: International Association for the Evaluation of Educational Achievement, *Second International Mathematics Study: U.S. Summary Report*, U.S. National Coordinating Center, University of Illinois at Urbana-Champaign (January 1985).

Science Indicators—1985

Appendix table 6-7. Items scored correctly on the International Survey of Twelfth Grade Mathematics, by selected countries: 1981-82

Topic	Total	United States		Japan	International[1]
		Precalculus	Calculus		
	Average percent				
Sets and relations	56	54	64	79	62
Number systems	40	38	48	68	50
Algebra	43	40	57	78	57
Geometry	31	30	38	60	42
Elementary functions calculus	29	25	49	66	44
Probability statistics	40	39	48	70	50

[1] The countries included, in addition to the United States, are: Belgium (Flemish); Belgium (French); Canada (British Columbia); Canada (Ontario); England and Wales; Finland; Hong Kong; Hungary; Israel; Japan; New Zealand; Scotland; Sweden; Thailand.

SOURCE: International Association for the Evaluation of Educational Achievement, *Second International Mathematics Study: U.S. Summary Report*, U.S. National Coordinating Center, University of Illinois at Urbana-Champaign (January 1985).

Science Indicators—1985

Appendix table 6-8. Shortages and field certification status of precollege teachers: 1984

Elementary and secondary	Total	Percent of all teachers	Shortage per 1000 teachers	No. not field certified	Percent of all not certified	Non-certified as percent of No. in field
Total:						
All levels	2,553,300	100.0	1.6	88,260	100.0	3.5
All science	131,100	5.1	1.7	5,360	6.1	4.1
Biology	28,800	1.1	1.7	1,090	1.2	3.8
Chemistry	14,600	0.6	1.9	590	0.7	4.1
Physics	8,700	0.3	4.5	490	0.6	5.6
Gen. & other	79,000	3.1	1.4	3,190	3.6	4.0
Mathematics	147,100	5.8	1.8	6,080	6.9	4.1
Other teachers	2,275,100	89.1	NA	76,820	87.0	3.4
Elementary:						
Total teachers	1,428,800	100.0	1.6	51,420	100.0	3.6
General science	15,500	1.1	3.9	620	1.2	4.0
Mathematics	20,800	1.5	4.1	870	1.7	4.2
other teachers	1,392,500	97.4	NA	49,930	97.1	3.6
Secondary:						
Total teachers	1,124,500	100.0	1.5	36,840	100.0	3.3
All science	115,600	10.3	1.4	4,730	12.8	4.1
Biology	28,800	2.6	1.7	1,090	2.9	3.8
Chemistry	14,600	1.3	1.9	590	1.6	4.1
Physics	8,700	0.8	4.5	490	1.3	5.6
Gen. & other	63,500	5.6	0.8	2,560	7.0	4.0
Mathematics	126,300	11.2	1.4	5,210	14.2	4.1
Other teachers	882,600	78.4	NA	26,900	73.0	3.0

SOURCE: National Center for Education Statistics, *1984 Survey of Teacher Demand and Shortage* (in process).

Science Indicators—1985

Appendix table 7-1. Distribution of persons very interested in science or technology: 1979-83

Age	Gender	Education	Percent very interested in science or technology			Number of Respondents (N)		
			1979	1981	1983	1979	1981	1983
All adults			46	47	61[1]	1,635	3,195	1,630
17-34	Male	No college	55	51	68	263	474	198
		College	65	66	63	66	175	138
	Female	No college	50	40	58	279	554	218
		College	53	61	62	64	117	117
35-54	Male	No college	39	49	59[1]	186	367	123
		College	74	58	72	57	125	110
	Female	No college	36	42	56[1]	210	440	166
		College	55	61	71	38	101	80
55 +	Male	No college	38	43	53[1]	171	293	153
		College	80	61	75	30	80	56
	Female	No college	34	38	49[1]	246	417	212
		College	65	48	73	26	50	59

[1] 1979-83 difference is significant at the .05 level.

SOURCE: Jon D. Miller, unpublished tabulations provided to the National Science Foundation.

Science Indicators—1985

Appendix table 7-2. Distribution of interest in science or technology among college students: 1983

Gender	Year in school	Intended occupation	Percent very interested	N
All students			51	2,011
Male	Freshman	Science or public service	67	158
		Other	51	167
	Sophomore	Science or public service	63	124
		Other	55	104
	Junior	Science or public service	65	110
		Other	55	120
	Senior	Science or public service	71	108
		Other	50	124
Female	Freshman	Science or public service	49	129
		Other	33	198
	Sophomore	Science or public service	68	94
		Other	37	133
	Junior	Science or public service	53	81
		Other	34	149
	Senior	Science or public service	51	71
		Other	37	138

SOURCE: Jon D. Miller, unpublished tabulations provided to the National Science Foundation.

Science Indicators—1985

Appendix table 7-3. Distribution of persons very well informed about science or technology: 1979-83

Age	Gender	Education	Percent well informed about science or technology 1979	1981	1983	N 1979	1981	1983
All adults			13	17	19[1]	1,635	3,195	1,630
17-34	Male	No college	20	23	23	262	474	198
		College	26	32	28	65	175	138
	Female	No college	8	11	15[1]	278	554	218
		College	14	26	15	64	117	117
35-54	Male	No college	14	13	20	187	367	123
		College	32	33	27	57	125	110
	Female	No college	6	10	13[1]	211	440	166
		College	8	20	15	38	101	81
55 +	Male	No college	13	22	23[1]	171	293	153
		College	43	28	30	30	81	56
	Female	No college	8	12	15[1]	246	417	211
		College	12	16	22	25	51	59

[1] 1979-83 difference is significant at the .05 level

SOURCE: Jon D. Miller, unpublished tabulations provided to the National Science Foundation.

Science Indicators—1985

Appendix table 7-4. Distribution of perception of being well informed about science or technology among college students: 1983

Gender	Year in school	Intended occupation	Percent well informed	N
All students			15	2,011
Male	Freshman	Science or public service	16	158
		Other	14	168
	Sophomore	Science or public service	22	124
		Other	23	104
	Junior	Science or public service	22	110
		Other	13	119
	Senior	Science or public service	29	108
		Other	14	124
Female	Freshman	Science or public service	14	129
		Other	9	198
	Sophomore	Science or public service	11	95
		Other	9	134
	Junior	Science or public service	17	81
		Other	10	150
	Senior	Science or public service	13	70
		Other	10	137

SOURCE: Jon D. Miller, unpublished tabulations provided to the National Science Foundation.

Science Indicators—1985

Appendix table 7-5. Distribution of persons attentive to science and technology: 1979-83

Age	Gender	Education	Percent very interested in science or technology			N		
			1979	1981	1983	1979	1981	1983
All adults			19	20	24[1]	1,635	3,195	1,630
17-34	Male	No college	22	26	26	275	475	243
		College	35	37	39	54	175	93
	Female	No college	13	11	13	290	554	246
		College	22	22	19	51	117	89
35-54	Male	No college	18	20	25	191	367	150
		College	40	30	38	52	125	84
	Female	No college	15	13	18	222	439	180
		College	37	30	37	27	101	67
55 +	Male	No college	16	17	26[1]	171	293	164
		College	48	34	37	31	80	46
	Female	No college	12	17	19[1]	249	418	225
		College	33	20	48	24	51	44

[1] 1979-83 difference is significant at the .05 level

SOURCE: Jon D. Miller, unpublished tabulations provided to the National Science Foundation.

Science Indicators—1985

Appendix table 7-6. Distribution of attentiveness to science and technology among college students: 1983

Gender	Year in school	Intended occupation	Percent Attentive	N
All students			25	2,011
Male	Freshman	Science or public service	35	158
		Other	25	167
	Sophomore	Science or public service	32	125
		Other	30	103
	Junior	Science or public service	39	111
		Other	33	120
	Senior	Science or public service	50	109
		Other	28	124
Female	Freshman	Science or public service	15	129
		Other	11	199
	Sophomore	Science or public service	32	95
		Other	13	133
	Junior	Science or public service	20	82
		Other	13	150
	Senior	Science or public service	29	70
		Other	16	137

SOURCE: Jon D. Miller, unpublished tabulations provided to the National Science Foundation.

Science Indicators—1985

Appendix table 7-7. Expectations concerning the future outcomes of science and technology, by level of attentiveness: 1979 and 1983

		Percent considering result "very likely"			
Result	Year	All adults	Attentive public	Interested public	Balance of public
A cure for the common forms of cancer	1979	46	55	53	41
	1983	57	68	60	50
A cure for mental retardation	1983	11	13	11	9
A way to put communities of people in outer space	1979	17	27	21	12
People working in a space station	1983	52	62	60	43
Humans communicating with alien beings	1983	14	17	17	11
Wars in space	1983	26	29	27	23
More efficient sources of cheap energy	1979	57	76	67	48
A safe method of disposing of nuclear wastes	1983	29	35	31	25
N	1979	1,635	307	337	991
N	1983	1,630	398	462	770

Now let me ask you to think about the long-term future. I am going to read you a list of possible scientific results and ask you how likely you think it is that each of these will be achieved in the next 25 years or so.

SOURCES: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U.S. Public toward Science and Technology* (Chicago: National Opinion Research Center, 1980); Jon D. Miller, *A National Survey of Adult Attitudes toward Science and Technology in the United States*. A report prepared for the Annenberg School of Communications, University of Pennsylvania, 1983.

Science Indicators—1985

Appendix table 7-8. Percent of public indicating "a great deal of confidence" in the people running selected institutions: 1973-84

Institution	1973	1974	1975	1976	1977	1978	1980	1982	1984
Medicine	54	60	50	54	51	46	52	46	52
Scientific community	37	45	38	43	41	36	41	38	47
Education	37	49	31	37	41	28	30	33	29
Organized religion	35	44	24	30	40	31	35	32	32
Military	32	40	35	39	36	29	28	31	37
Major companies	29	31	19	22	27	22	27	23	32
Press	23	26	24	28	25	20	22	18	17
Television	19	23	18	19	17	14	16	14	13
Organized labor	15	18	10	12	15	11	15	12	9
Executive branch	29	14	13	13	28	12	12	19	19
Congress	23	17	13	14	19	13	9	13	13
Supreme court	31	33	31	35	35	28	25	30	35
N =	1,504	1,484	1,490	1,499	1,530	1,532	1,468	1,506	943

I am going to name some institutions in this country. As far as the people running these institutions are concerned, would you say you have a great deal of confidence, only some confidence, or hardly any confidence at all in them?

SOURCES: James A. Davis and Tom W. Smith, *General Social Surveys Cumulative File, 1972-1984* (Ann Arbor: Inter-University Consortium for Political and Social Research, 1983), pp. 144-9. Unpublished 1984 data provided by Tom W. Smith.

See figure 7-1.

Science Indicators—1985

Appendix table 7-9. Public willingness to restrain scientific inquiry: 1979 and 1983

Percent willing to prohibit the following types of scientific inquiry:	Year	All adults	Attentive public	Interested public	Balance of public
Studies that might enable most people in society to live to be 100 or more . . .	1979	29	21	24	34
	1983	32	22	30	38
Studies that could allow parents to select the sex of their child	1983	62	20	29	50
Studies that might allow scientists to create new forms of life	1979	65	52	66	69
Studies that could allow scientists to create new forms of plant and animal life	1983	46	19	29	52
Studies that might lead to precise weather control and modification	1979	28	18	26	32
Studies that might discover intelligent beings in outer space	1979	36	18	29	44
	1983	38	18	25	58
N	1979	1.635	307	337	991
N	1983	1.630	398	462	770

In terms of some specific kinds of research, do you think that scientists should or should not be allowed to conduct: ?

SOURCES: Jon D. Miller, Kenneth Prewitt, and Robert Pearson, *The Attitudes of the U.S. Public toward Science and Technology* (Chicago: National Opinion Research Center, 1980); Jon D. Miller, *A National Survey of Adult Attitudes toward Science and Technology in the United States*. A report prepared for the Annenberg School of Communications, University of Pennsylvania, 1983.

Science Indicators—1985

Appendix II
Contributors and Reviewers

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